End-Use Savings Shapes

Public Data Set Release: Commercial 2024 Release 1

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NREL Webinar

April 25, 2024

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Logistics

- We are recording the webinar.
- Because of the large number of participants, everyone is muted.
- Please use the Q&A box to send us questions at any time during the presentation.
- The webinar slides and data set are publicly available now.

Acknowledgments

This work is the culmination of several years of research efforts.

We would like to thank the following for helping make this possible:

- ComStock™ and ResStock™ teams
- OpenStudio® and EnergyPlus® teams
- Lawrence Berkeley National Laboratory
- Argonne National Laboratory
- Pacific Northwest National Laboratory
- U.S. Department of Energy Building Technologies Office
- U.S. Department of Energy Geothermal Technologies Office.

Agenda

1. End-Use Savings Shapes: Background
2. Our Approach to Stock Modeling with ComStock
3. End-Use Savings Shapes: 2024 Release 1
4. Accessing the Data Set
5. Next Steps
6. Q&A

Project Background

Problem Statement

A lack of credible and relevant information results in confusion and inaction by cities, states, utilities, and other major stakeholders.

Will electrification of buildings…

- Reduce carbon emissions in my city?
- Be feasible in my building stock?
- Overload the grid?

EULP and EUSS Road Map

- The **End-Use Load Profiles** (EULP) project:
  - Created a public data set for calibrated energy models of the U.S. commercial and residential building stock using ComStock and ResStock.

- The **End-Use Savings Shapes** (EUSS) follow-on project:
  - Adds the impact of several energy efficiency and electrification "what-if" scenarios ("measures") to the baseline stock models.
  - Residential EUSS Release 1 was presented September 2022.
  - Commercial EUSS 2023 Release 1 was presented March 2023.
  - Commercial EUSS 2023 Release 2 was presented October 2023.
  - **Residential EUSS 2024 Release 2** was presented April 2024.
  - **This presentation is for Commercial EUSS 2024 Release 1.**

Commercial EUSS Approach

End-Use Load Profiles (EULP)

Describe how and when energy is used in buildings **today.**

Public database of 350,000 individual building models and their energy end-use load profiles.

End-Use Savings Shapes (EUSS)

Describe how and when energy is used in **"what-if" scenarios.**

Adds measure impact profiles for energy efficiency and electrification packages versus the ComStock baseline.

EUSS 2024 Commercial Release 1 Data Set represents the building stock circa 2018 using 2018 actual meteorological year (AMY) weather.

Alignment and Impact

We are putting information in the hands of decision makers.

This effort supports the U.S. Department of Energy's (DOE) goals to increase building energy efficiency, accelerate building electrification, and to do so in ways that prioritize equity, affordability, and resilience.

What the Data Sets Provide

- Building stock characterization
- How, where, and when buildings use energy
- Information on time-sensitive value of energy resources
- Potential impacts of energy efficiency, electrification, and demand flexibility.

How the Information Is Used

- Electrification planning
- Emissions analysis
- Decarbonization decision-making
- Utility-integrated resource plans and load forecasts
- Policy and rate design.

2024 Release 1: What is the new data set?

Updated ComStock Model

- Improvements since last release

Measures From Previous Releases

- 17 existing measures, re-simulated with the updated ComStock baseline

New 2024 Release 1 Measures

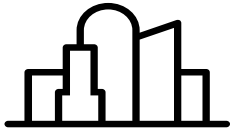
- 12 new measures/packages

Previous commercial EUSS data sets will remain available.

Our Approach to Stock Modeling

ComStock Workflow

ComStock



Building stock characteristics database

- Variation in building type, size, location, vintage, heating fuel, etc.
- **Over 80** probability distributions of various attributes.

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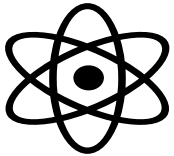

Physics-based computer modeling

- Representative set of 350K OpenStudio energy models.
- Apply “what if” scenarios to models (electrification, etc.)

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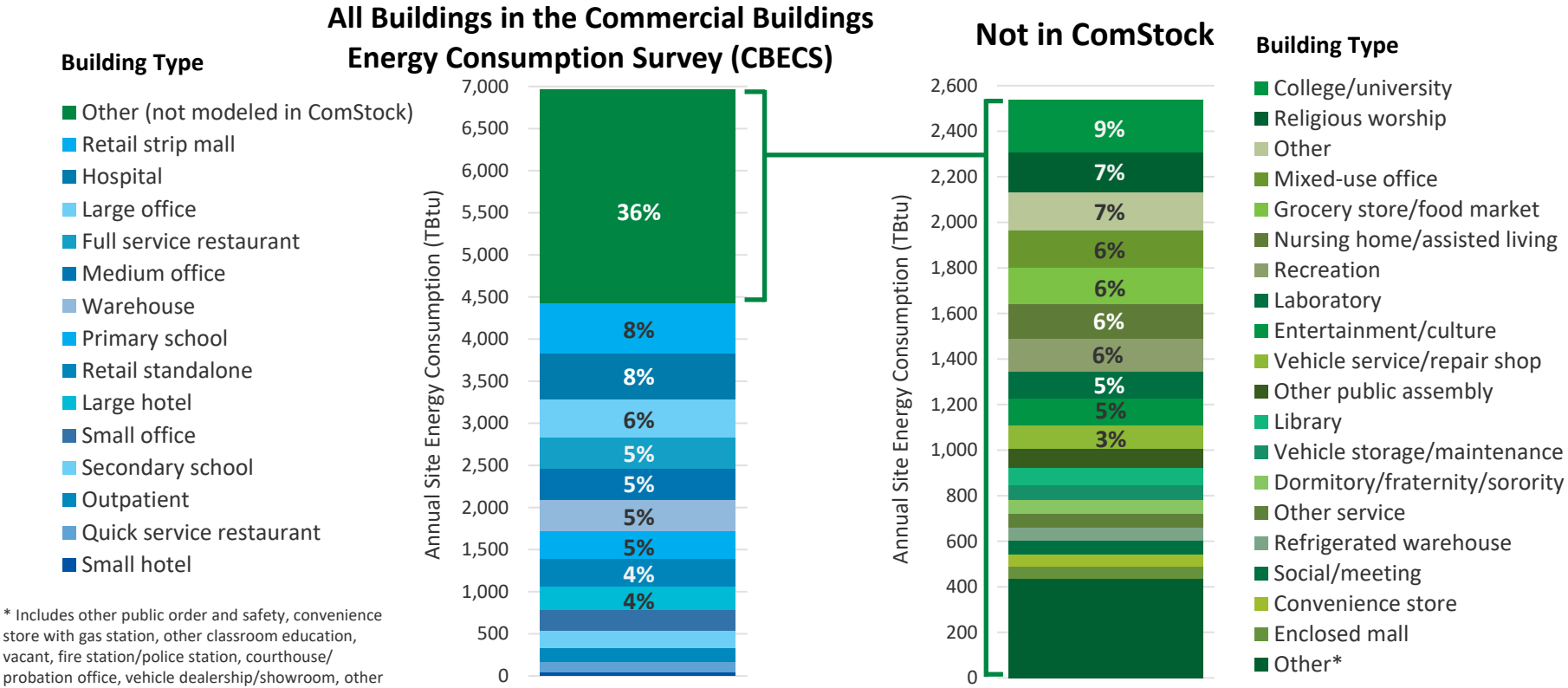
High-performance computing

- Simulate models.
- Process and publish data.
- Apply scaling factors.

What Does ComStock Model?



* Includes other public order and safety, convenience store with gas station, other classroom education, vacant, fire station/police station, courthouse/ probation office, vehicle dealership/showroom, other lodging, preschool/daycare, repair shop, post office/postal center, other food service, other food sales.

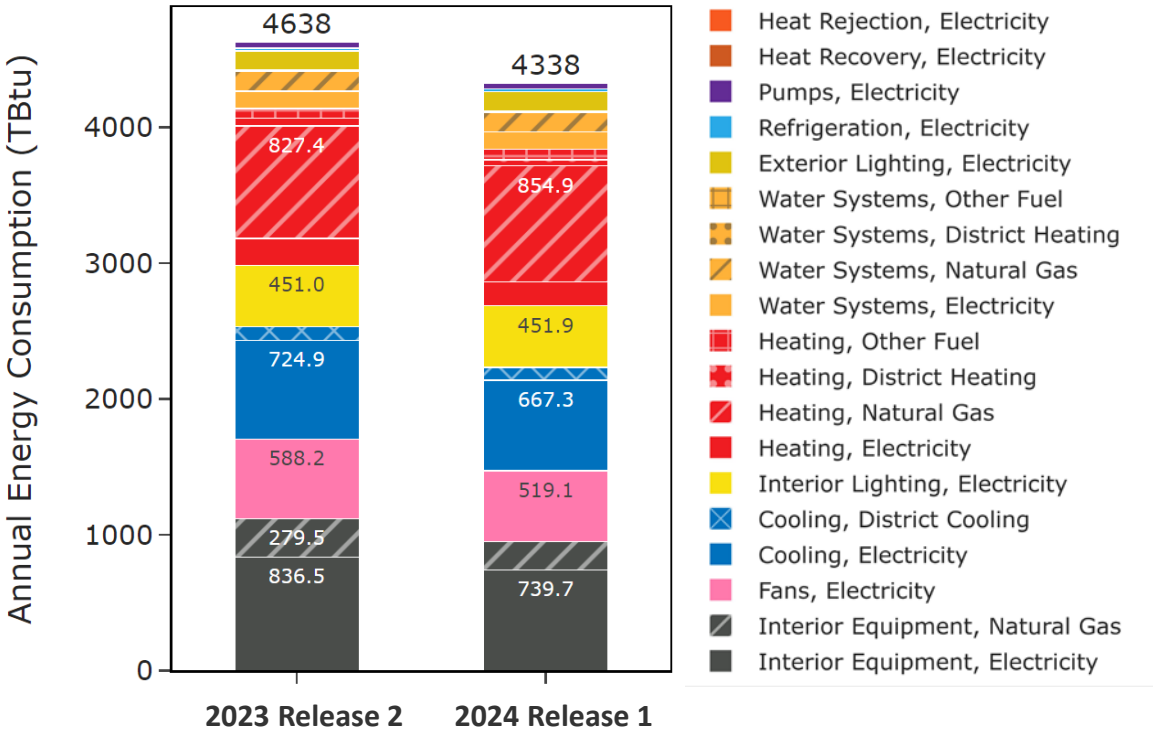
ComStock Baseline Updates Since Last Release

Continuous Improvements:

- Warehouse HVAC and thermostat updates
- Updated occupancy schedules
- Implementation of utility bills
- Kitchen equipment updates
- Updated to OpenStudio 3.7.0
- General bug fixes.

Potential Future Improvements:

- New building types
  - Grocery store
  - Worship
- Improved zoning methodology
- Improved hot water usage methodology
- Further calibration.



Full change log available on GitHub

ComStock Documentation

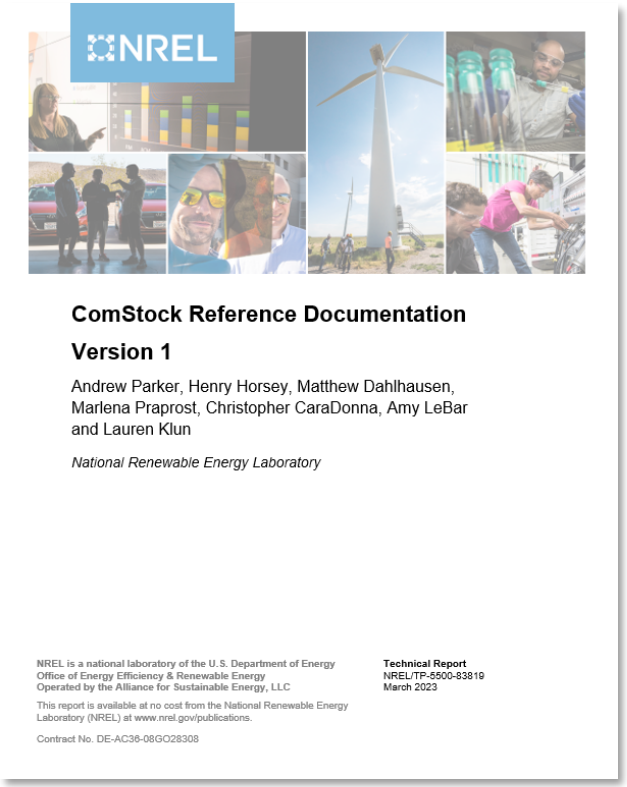
ComStock documentation is available.

This document serves as a guide and resource to the methodology and assumptions behind ComStock.

Links

- [ComStock Documentation]
- [Introduction to ComStock slides]

Questions? Email comstock@nrel.gov



NREL

ComStock Reference Documentation

Version 1

Andrew Parker, Henry Horsey, Matthew Dahlhausen, Marlena Praprost, Christopher CaraDonna, Amy LeBar and Lauren Klun

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Technical Report
NREL/TP-5500-83819
March 2023

New ComStock Feature – Utility Bills

Utility bill estimates reflect utility rates circa 2022.

ComStock now estimates 2022 utility bills for several primary fuels consumed in buildings.

On-Site Combustion Fuels

- Natural Gas: 2022 EIA commercial natural gas prices by state
- Propane and fuel oil: 2021-2022 Winter EIA residential fuel oil and propane
  - Residential used because sub-national commercial data are not available.

Electricity

- Rates from OpenEI Utility Rate Database (URDB)
  - Include time-of-use periods, demand charges, ratchets, etc.
  - All applicable rates applied per building; **min, max, and average available in data set**
- If no URDB rate for building: EIA commercial average by state is used
  - ~13% of ComStock.

District Heating/Cooling – Rates not included in ComStock.

Greenhouse Gas Emissions

Greenhouse gas emissions in data set represent equivalent CO_2 emissions.

Electricity

- Three grid electricity scenarios compared today; more included in published data set.
- This work does not imply a preference for any grid emission scenario.

Electricity Grid Scenario	Start Year	Levelization Period (3% discount rate)	Data Source
LRMER High RE Cost*	2023	15 years	NREL Cambium [1]
LRMER Low RE Cost	2023	15 years	NREL Cambium [1]
eGRID*	2021	N/A	EPA eGRID [2]

On-Site Combustion Fuels

- Values from Table 7.1.2(1) of draft ANSI/RESNET/ICCC 301 [3]

Natural Gas	147.3 lb/mmbtu (228.0 kg/MWh)
Propane	177.8 lb/mmbtu (182.3 kg/MWh)
Fuel Oil	195.9 lb/mmbtu (303.2 kg/MWh)

* LRMER = Long Run Marginal Emissions Rate; RE = renewable energy; eGRID = Emissions & Generation Resource Integrated Database

Please Note

- The ComStock model is **continuously updated** with new information, methods, and improved quality assurance/quality control procedures. Data sets are released in 6-month increments; 3-month increments for 2025.

- Measures are **not intended to be comprehensive** of a given technology. As additional data becomes available, measure results may be updated.

- The measure result summaries in this presentation are intended to be **high-level observations** to introduce the data set. For more detailed conclusions, please watch for updates on the publications section of our website or explore the data set.

End-Use Savings Shapes: Commercial 2024 Release 1

Technology modeling, results observations, and discussion

ComStock Measure Documentation Website

Comprehensive documentation is available for each measure.

Describes the modeling methodology, assumptions, limitations, relevant ComStock baseline features, and observations from results.

Also find EUSS webinar slides and recordings.

Access at: ComStock Documentation Site

Existing Measures From Previous Releases

2023 Release 1 Measure List	2023 Release 2 Measure List
Heat Pump Rooftop Unit (HP-RTU) With Electric Resistance Backup	Heat Pump Rooftop Unit (HP-RTU) With Original Fuel Backup
Rooftop Ventilator + HP Split System	Air to Water HP Boiler Retrofit With Gas Backup
Air to Water HP Boiler Retrofit With Electric Backup	Variable Refrigerant Flow (VRF) With Dedicated Outdoor Air System (DOAS)
LED Lighting	Demand Control Ventilation (DCV)
Exterior Wall Insulation	Energy Recovery
Secondary Windows	Package 1: Envelope
Window Replacement	Package 2: Lighting + HVAC
Window Film	Package 3: Envelope + Lighting + HVAC
Roof Insulation	

These are included in the new data set, but not discussed in this presentation.

New EUSS 2024 Release 1 Measures

Measure Name	Description	% of Stock Floor Area
Variable Speed Heat Pump Rooftop Unit (HP-RTU), Electric Backup, Energy Recovery (ER)	Replace gas furnace and electric resistance RTUs with variable-speed HP-RTU with electric backup and integrated heat or energy recovery.	33%
Advanced Rooftop Unit (RTU) Controls	Retrofits existing single-zone constant air volume RTUs to include variable-speed fan, economizer, and demand control ventilation.	39%
Unoccupied Air Handling Unit (AHU) Control	Aligns outdoor air and fan operation to occupancy schedules for existing AHUs.	45%
Air Side Economizers for AHUs	Adds air-side economizers to existing AHUs.	66%
VRF With 25% Upsizing Allowance	Replaces AHUs and RTUs with a cold climate VRF that sizes the heat pump up to 25% beyond the design cooling load when needed for heating. Electric backup is used for remaining load.	49%
Electric Cooking Equipment	Replaces primary gas commercial cooking equipment with similar electric alternatives.	38%
Package 5, Variable Speed HP RTU or HP Boilers + DCV + Energy Recovery + Economizer	Combines several HVAC electrification and efficiency measures: variable-speed HP-RTU or HP boiler with demand control ventilation, energy/heat recovery, and economizers.	85%

New EUSS 2024 Release 1 Measures (cont'd)

Measure Name	Description	% of Stock Floor Area
Ground-Source Heat Pump Measures		
Packaged Water-to-Air Geothermal Heat Pump	Replace rooftop units and packaged air handling units with ground-coupled water-to-air packaged rooftop unit. Includes economizer and demand control ventilation.	56%
Ground-Coupled Console Water-to-Air Heat Pump	Replace PTACs, residential-style systems, baseboards, and unit heaters with ground-coupled water-to-air terminal heat pumps.	11%
Central Ground-Source Water-to-Water Heat Pump	Retrofit central hydronic systems (e.g., boilers, chillers) with central ground-coupled water-to-water heat pump.	13%
Comprehensive Geothermal Heat Pump Package, Hydronic GHP, Packaged GHP, or Console GHP	Comprehensive ground-source heat pump packages that combines all 3 ground-source heat pump scenarios.	80%
Demand Flexibility Measures		
Thermostat Control for Load Shedding	Relaxes thermostat setpoints by 2°C for 4 hours during daily building peak window **in large offices**. Ramp back setpoints in 2-hour rebound control after peak window.	10%
Thermostat Control for Load Shifting	Tightens thermostat setpoint by 1°C for 2 hours prior to 4-hour building daily peak window **in large offices.**	10%

Variable-Speed Heat Pump Rooftop Unit (HP-RTU), Electric Backup, Heat or Energy Recovery (H/ER)

Variable-Speed HP-RTU With H/ER

Measure Concept

- Replace gas and electric RTUs with variable-speed HP-RTUs
- Includes air-side heat or energy recovery (H/ER) to reduce ventilation loads.

HP-RTU Performance

- **Sizing:** Sized to design cooling load; backup heat used for remainder
- **Backup Heat:** Electric resistance
- **Compressor Lockout:** 0°F
- **Defrost:** Reverse cycle
- **Performance Data Source:** Lab and manufacturer performance data.

Applicability

- Buildings w/ gas or electric resistance RTUs
  - **~33%** of stock floor area, varies regionally.

Heat/Energy Recovery Type

Humid Climates

- Membrane fixed-plate **energy recovery**
- Sensible and latent recovery
- Includes bypass.

All Other Climates

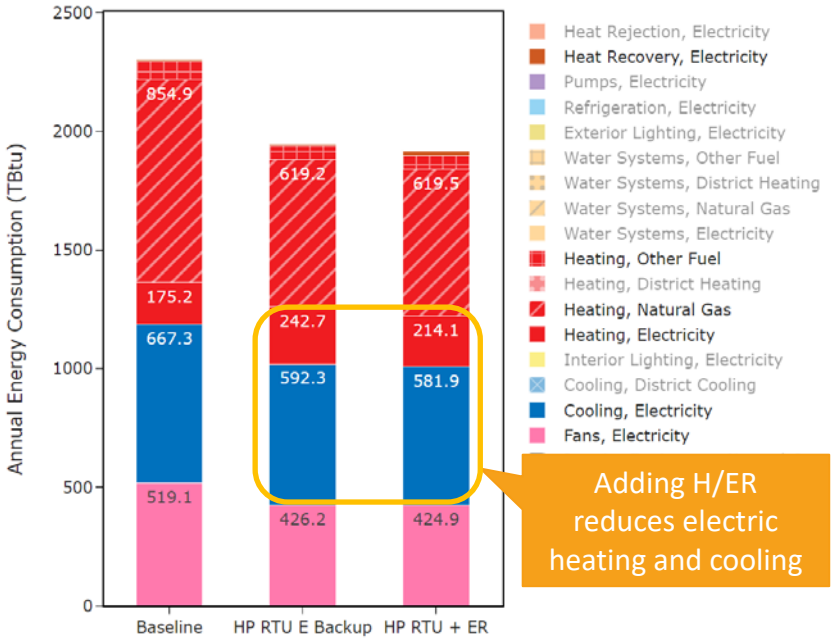
- Aluminum fixed-plate **heat recovery**
- Sensible-only recovery
- Includes bypass.

Variable-Speed HP-RTU With H/ER

HP-RTU with H/ER (HP-RTU+ER) vs. baseline:

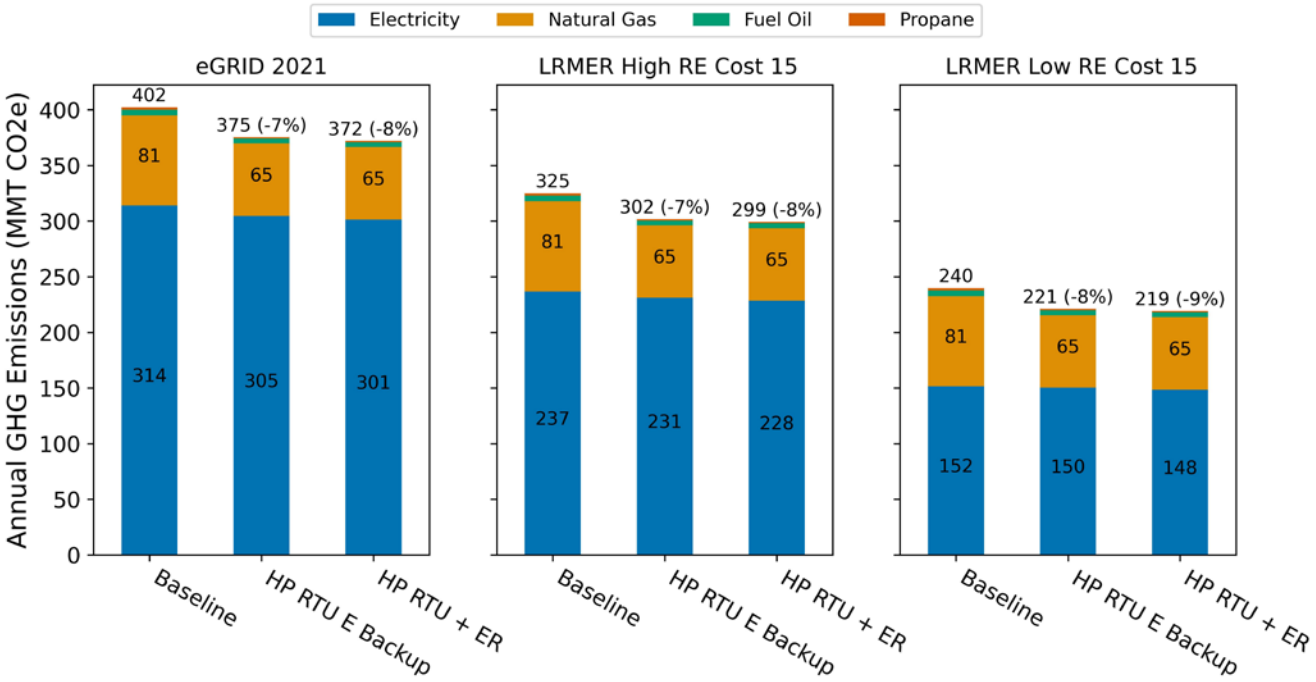
- **28%** stock **heating gas** savings (235 TBtu)
- **-22%** stock **heating electricity** savings (-39 TBtu)
- **13%** stock **cooling electricity** savings (85 Tbtu)
- **15%** stock **fan+heat recovery electricity** savings (81 Tbtu)
- Electrifying gas RTUs reduces natural gas heating and increases electric heating
- High-efficiency, variable-speed fans reduce fan energy despite added fan pressure from energy recovery
- Adding heat/energy recovery reduces heating and cooling energy.

Stock Site Energy by Fuel and End Use



E Backup = HP-RTU with Electric Backup, No H/ER
ER = HP-RTU with Electric Backup, with H/ER

Variable-Speed HP-RTU With H/ER; Greenhouse Gas Emissions

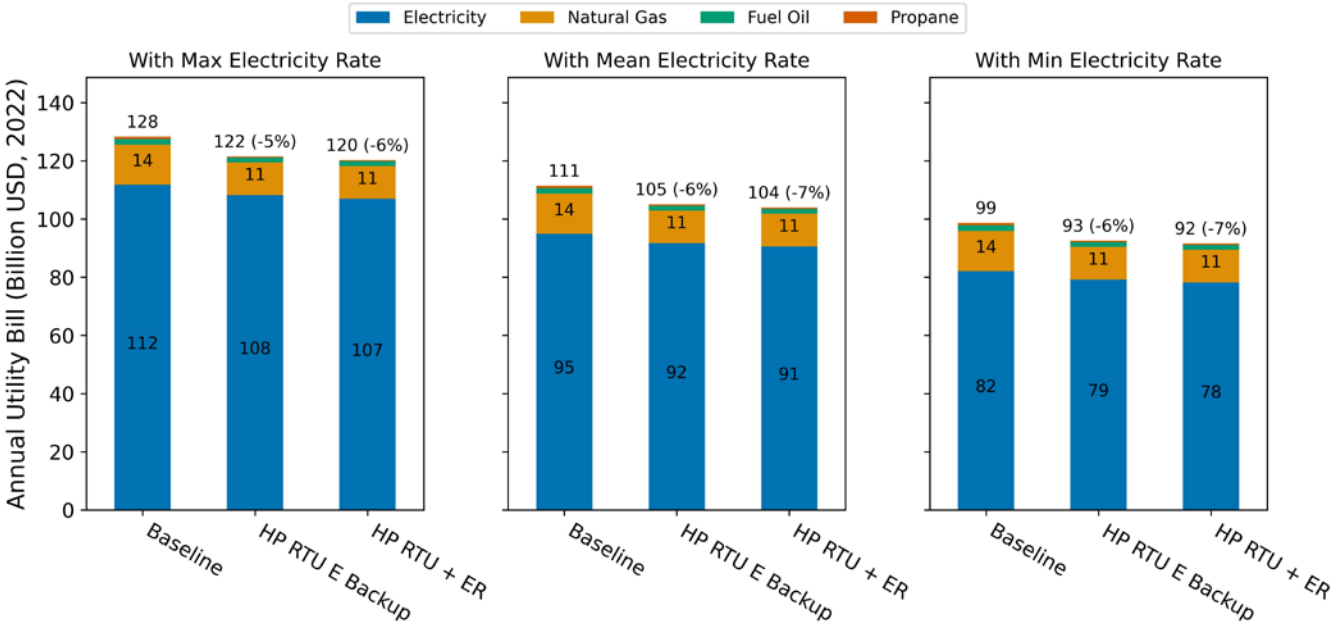


- Net emissions avoided across all electricity grid scenarios.
- Avoided gas emissions from transitioning gas-fired RTUs to electric HP-RTUs.
- Avoided electricity emissions from fan and cooling savings, despite increased electric heating.
- Adding H/ER further avoids emissions.

Electricity Grid Scenarios

- eGRID 2021 = Emissions & Generation Resource Integrated Database, year 2021
- LRMER High RE Cost 15 = Cambium Long Run Marginal Emissions Rate, high renewable energy cost, 15 year
- LRMER Low RE Cost 15 = Cambium Long Run Marginal Emissions Rate, low renewable energy cost, 15 year

Variable-Speed HP-RTU With H/ER; Energy Bills



- Comprehensive energy bill savings across all electricity rate structure scenarios.
- Over **$6 billion** of annual stock bill savings with the HP-RTU scenario applied.
- Over **$7 billion** of annual stock bill savings when heat/energy recovery is added to the HP-RTU scenario.
- Results vary across stock; consider the distributions.

Electricity Rate Structure Scenarios:

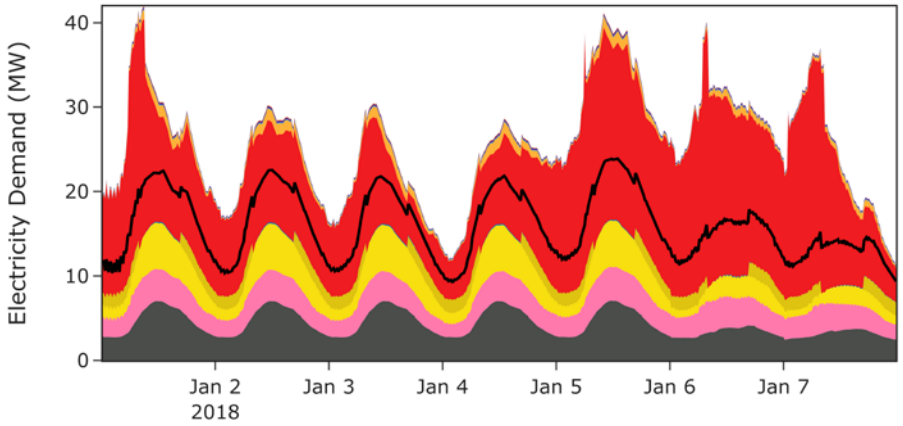
- Max electricity rate: Maximum of available URDB electricity rate used for each location
- Mean Electricity rate: Average of all available URDB electricity rates used for each location
- Min Electricity rate: Minimum of available URDB electricity rate used for each location

Variable-Speed HP-RTU With H/ER; Peak Winter Week

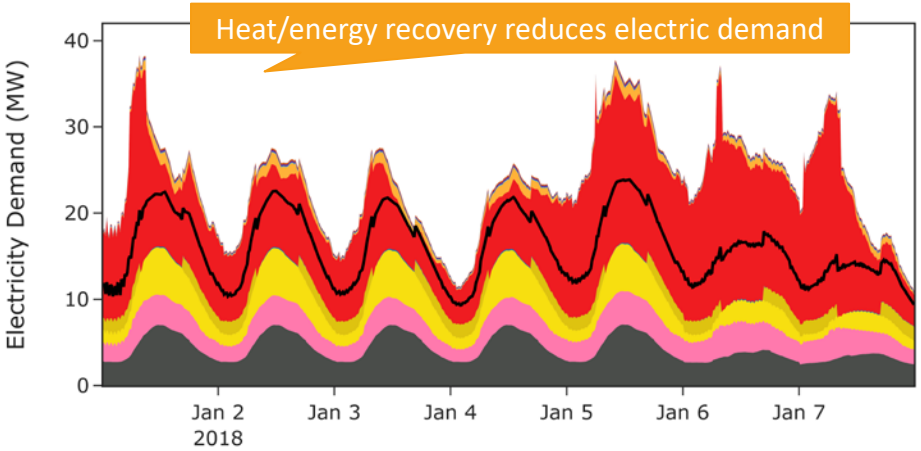
Sample Location: Rochester, NY
Time step: 15 minutes

Scope: Total commercial stock
Fuel: Electricity

HP-RTU Scenario, No Heat/Energy Recovery



HP-RTU Scenario, Heat/Energy Recovery



Baseline Total	heat_recovery	heat_rejection
pumps	refrigeration	water_systems
heating	cooling	exterior_lighting
interior_lighting	fans	interior_equipment

Note that load profiles are **heavily influenced** by assumptions for heat pump sizing routine, lockout temperature, and performance curves.

Advanced Rooftop Unit (RTU) Controls

Advanced Rooftop Unit (RTU) Controls

Measure Concept

Retrofit existing single-zone constant-volume RTUs with:

- Variable-speed drives for fans
- Integrated economizers
- Demand-controlled ventilation (DCV).

Single Zone VAV Operation

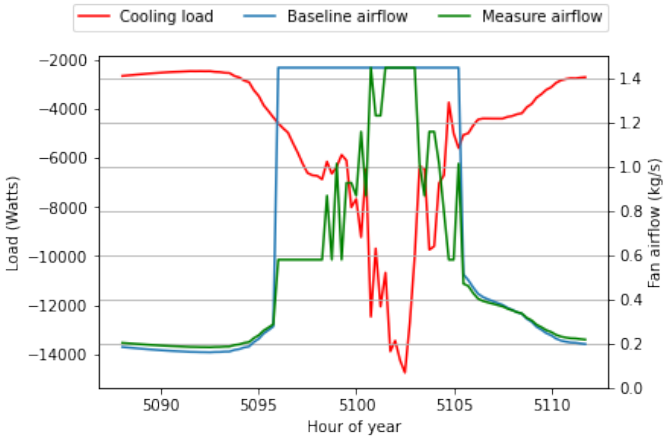
Operation follows common retrofit kits:

- **High load:** Full design airflow
- **Low-load or ventilation only:** 40% of design airflow (or minimum outdoor air)
- Discrete fan speeds between high and low loads.

Applicability

- Existing single-zone RTUs
- Applicable to **39%** of stock floor area
- Economizers and DCV added to RTUs that do not already have them

Example Single Zone VAV Operation

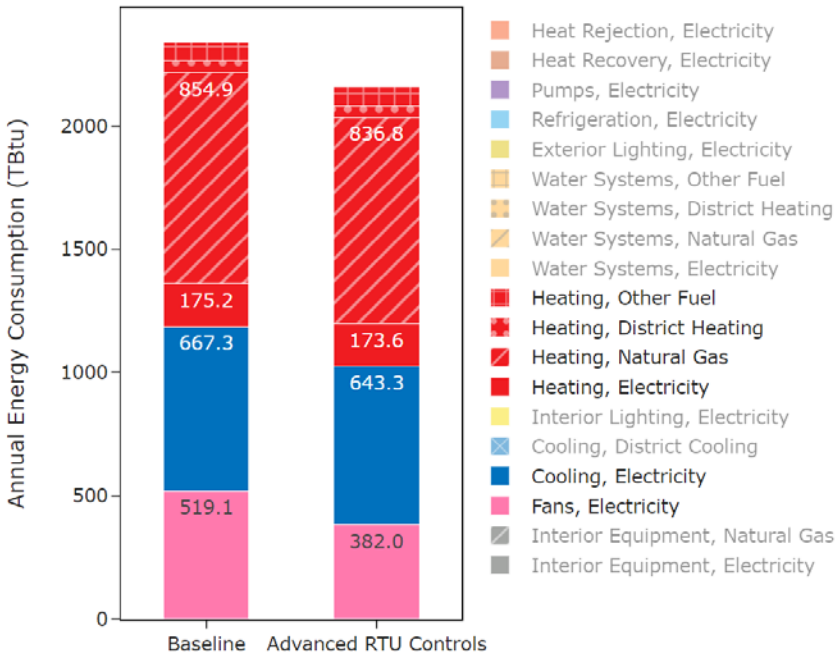


Advanced Rooftop Unit (RTU) Controls

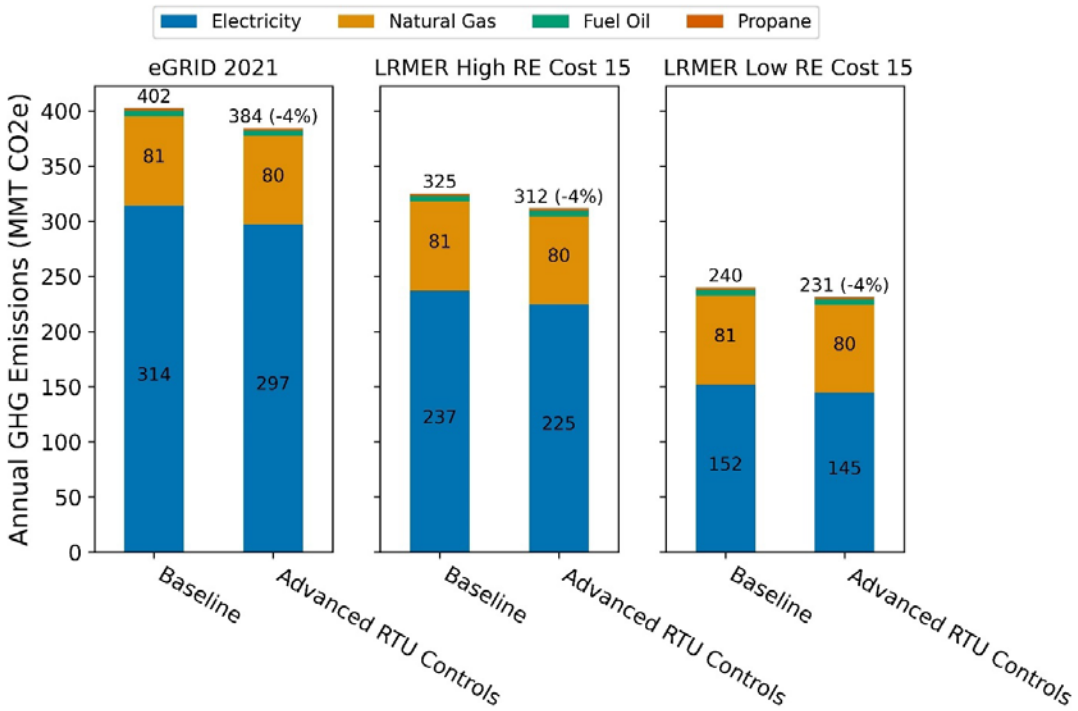
Advanced RTU controls vs. baseline:

- **26%** stock **fan electricity** savings (137 TBtu)
- **3.6%** stock **cooling electricity** savings (24 TBtu)
- **2.1%** stock **heating gas** savings (18 Tbtu)
- Fan savings from reduced fan power during low-load operation
- Heating savings from DCV, despite increased heating loads from reduced fan heat
- Cooling savings from economizing, DCV, and reduction in fan heat.

Stock Site Energy by Fuel and End Use



Advanced Rooftop Unit (RTU) Controls



- Net emissions avoided across comprehensive grid scenarios and fuel types presented.
- Most emissions avoided are from reductions in electricity usage.

Electricity Grid Scenarios

- eGRID 2021 = Emissions & Generation Resource Integrated Database, year 2021
- LRMER High RE Cost 15 = Cambium Long Run Marginal Emissions Rate, high renewable energy cost, 15 year
- LRMER Low RE Cost 15 = Cambium Long Run Marginal Emissions Rate, low renewable energy cost, 15 year

Unoccupied Air Handling Unit (AHU) Control

Unoccupied AHU Control

Measure Concept

- Aligns AHU fan and outdoor air scheduling to building occupancy (Scheme 3 below)
- ComStock baseline reflects existing unoccupied fan and ventilation operation under several schemes.

Applicability

- AHU-based systems with Scheme 1 or 2
  - About **45%** of stock floor area
  - Not applicable to hospitals, outpatient facilities, schools, facilities operating 24/7, or to DOAS.

Measure transitions buildings following scheme 1 or 2 to scheme 3

ComStock Baseline Unoccupied Fan/Ventilation Schemes

Scheme 1

- Full AHU operation during unoccupied hours.

Scheme 2

- AHUs off during unoccupied hours
- Fans cycle with ventilation to meet loads.

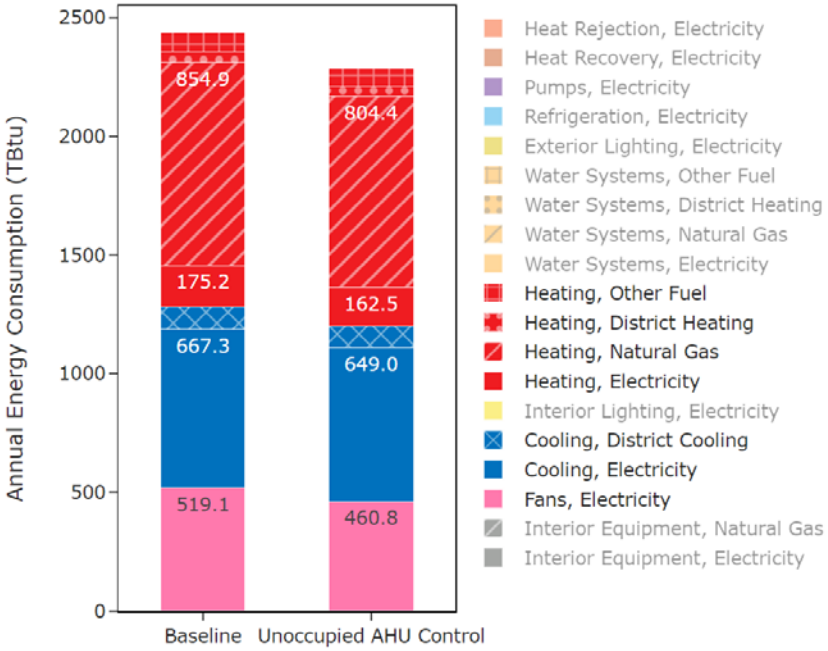
Scheme 3

- AHUs off during unoccupied hours
- Fans cycle without ventilation to meet loads.

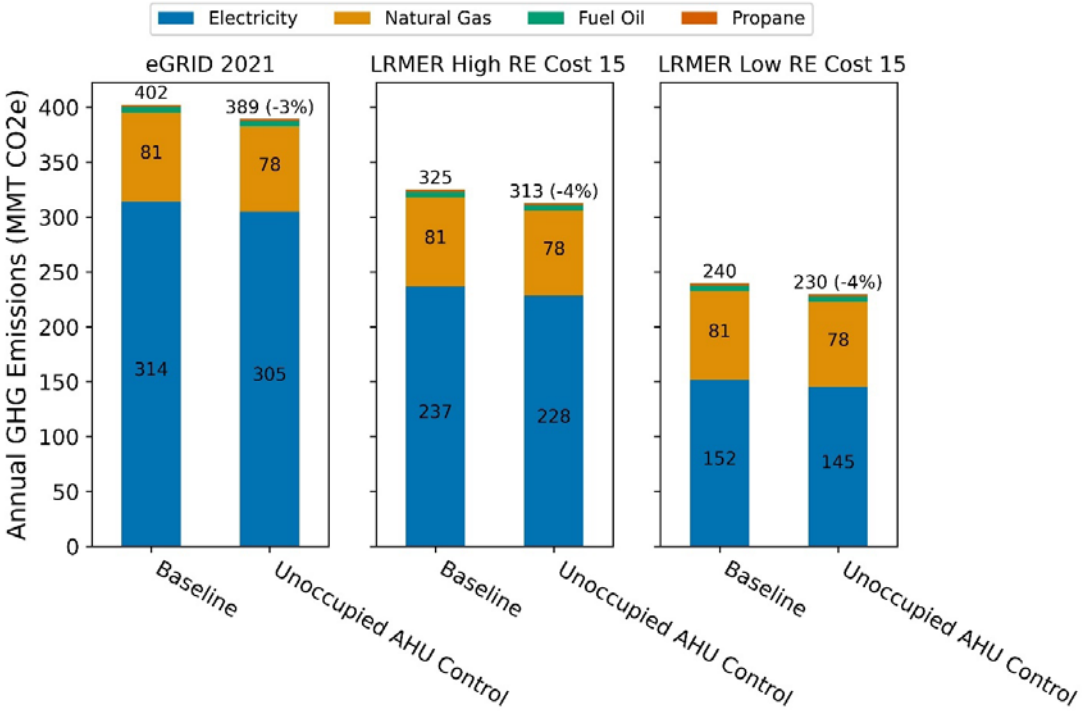
Unoccupied AHU Control

- **11%** stock **fan** savings (58 TBtu)
- **7.2%** stock **heating electricity** savings (13 TBtu)
- **5.6%** stock **heating gas** savings (50 TBtu)
- **2.7%** stock **cooling electricity** savings (18 TBtu)
- Fan savings from reduced unoccupied operation to match occupancy
- Reduction in heating loads, and to a lesser extent cooling, from elimination of ventilation during unoccupied periods
- Some increased cooling loads in models without economizers.

Stock Site Energy by Fuel and End Use



Unoccupied AHU Control



- Net emissions avoided across comprehensive grid scenarios and fuel types presented.
- Avoided emissions are from both gas and electricity.

Electricity Grid Scenarios

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- LRMER Low RE Cost 15 = Cambium Long Run Marginal Emissions Rate, low renewable energy cost, 15 year

Air-Side Economizers for Air Handling Units (AHU)

Air-Side Economizers for AHUs

Measure Concept

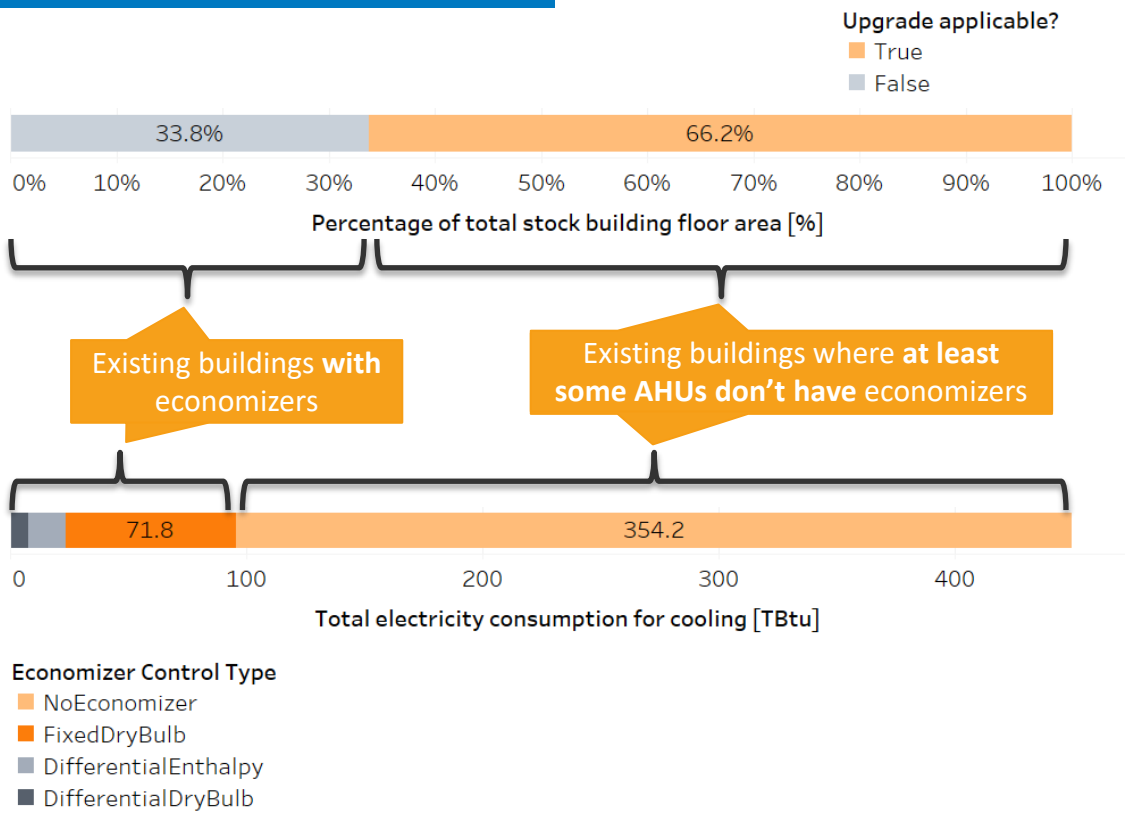
- Adds air-side economizers to existing air handlers.

Technology Specifications

- Economizer configuration following energy code guidelines.

Applicability

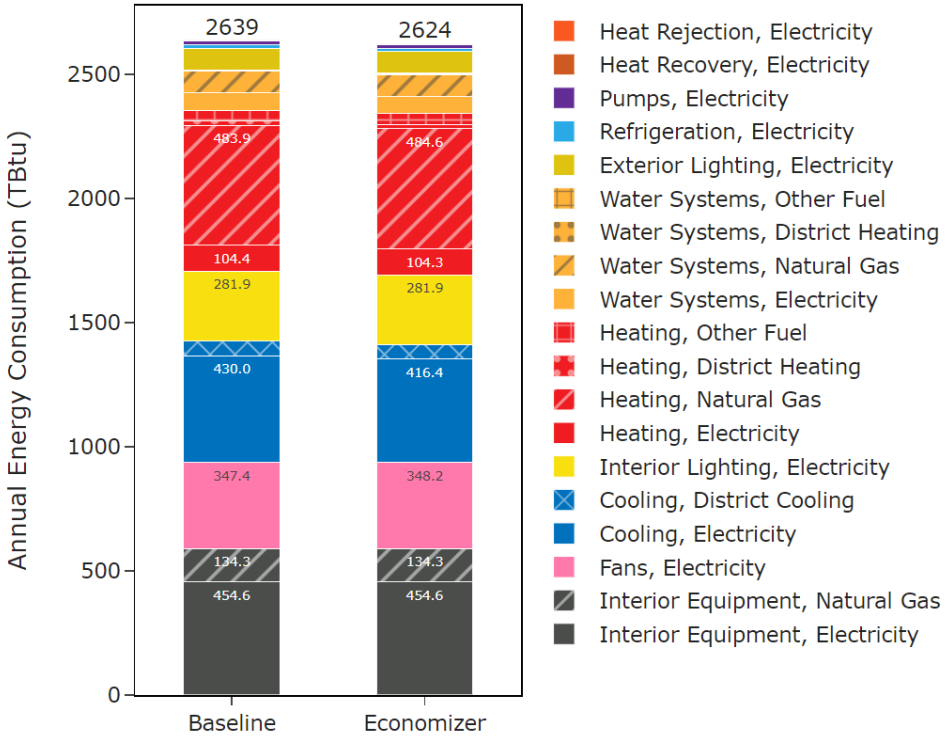
- Air handlers without existing economizers.
- Applicable to **~66%** of stock building floor area.



Air-Side Economizers for AHUs

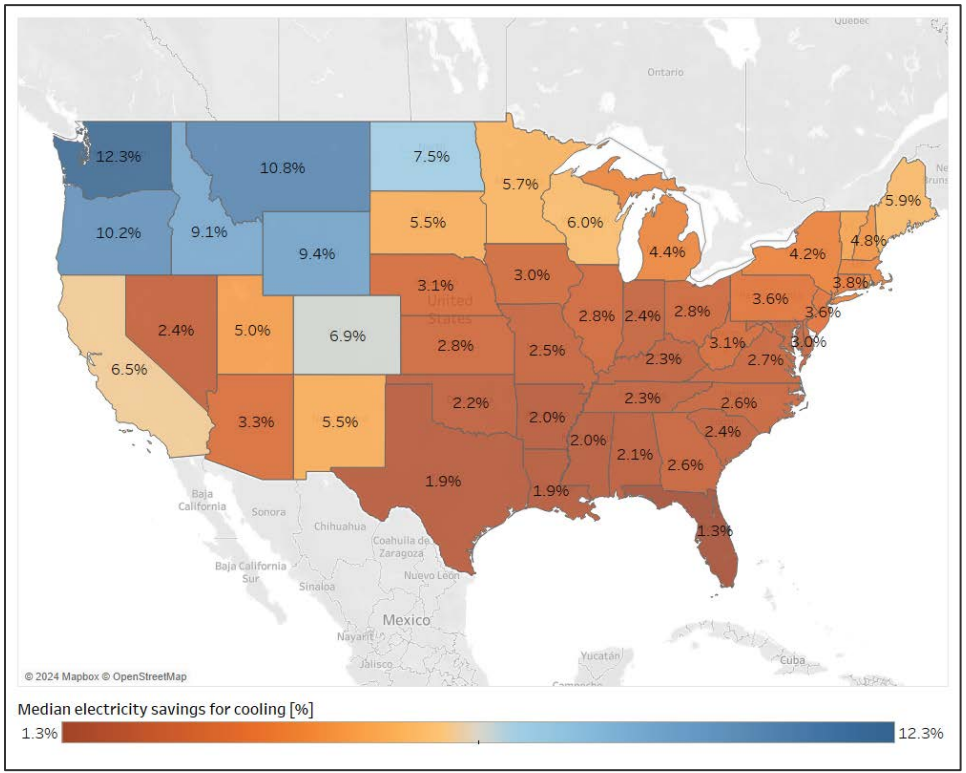
- **2.0%** stock **cooling electricity** savings (13.6 TBtu)
- Cooling savings from leveraging favorable cold outdoor air when building needs cooling
- Lower overall stock-level impact due to:
  - Many AHUs already having economizers for energy codes
  - Economizers reduce cooling load, but only during specific favorable conditions.

Site Energy by Fuel and End Use



Air-Side Economizers for AHUs

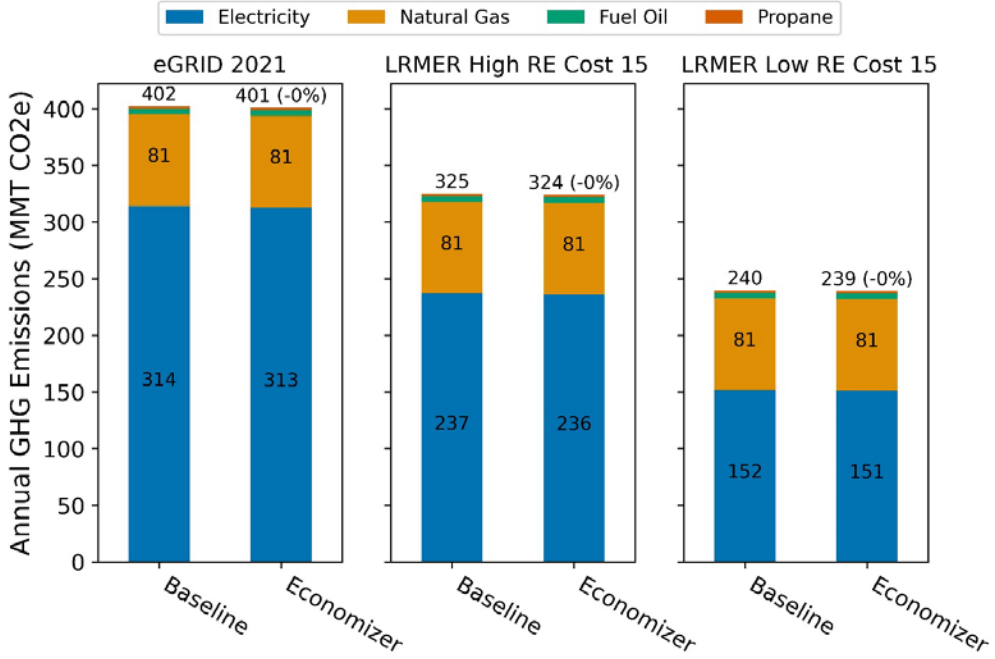
Median Cooling % Electricity Savings by State



- Savings depends on many factors:
  - Cooling demand
  - Regional outdoor air conditions
  - Return air conditions
  - Outdoor air requirements
  - Economizer configuration
  - And more.

- Economizer requirements have long been included in energy codes in many climates, limiting the opportunity and extent of stock-level savings.

Air-Side Economizers for AHUs



- Net emissions avoided across all comprehensive grid scenarios and fuel types presented.
- Stock emissions avoided varies between 0.2-0.4%.

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Variable Refrigerant Flow (VRF) With 25% Upsizing Allowance for Heating

VRF With 25% Upsizing Allowance for Heating

Measure Concept

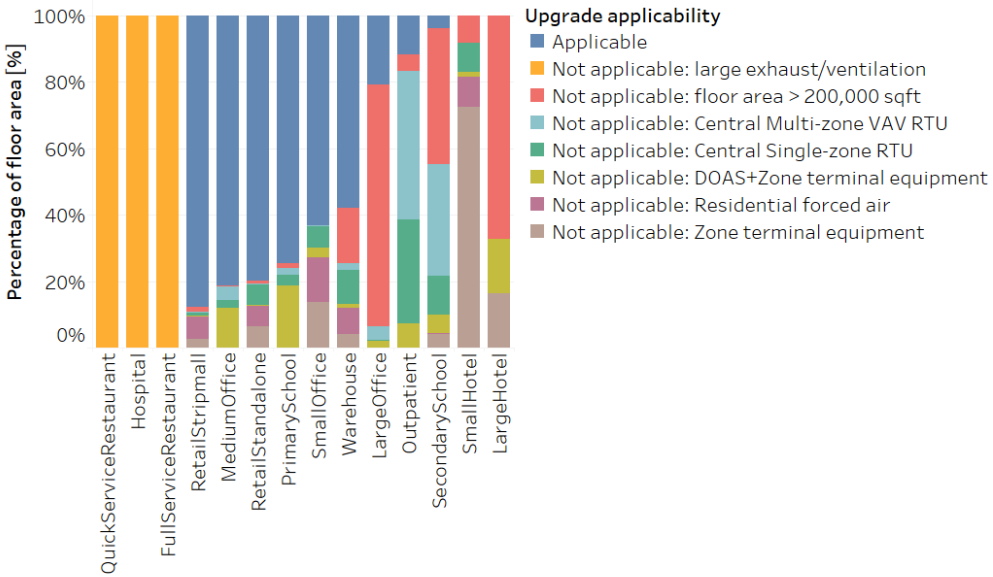
- Replace RTUs/variable air volumes (VAVs) with VRF with dedicated outdoor air system (DOAS)
- Cold climate VRF technology (rated to −22°F)
- Outdoor ventilation air provided by heat/energy recovery DOAS with electric heat and direct expansion (DX) cooling
- Decoupled ventilation.

VRF Performance

- Sizing: allowing up to 25% upsizing (from design cooling load) for heating dominant zones
- Supplemental heat: Electric resistance
- Compressor lockout: −22°F
- Performance data source: Manufacturer data.

Applicability

- Buildings with RTUs/VAVs
- Limitations = building/space type, size, indoor unit count, or original fuel type (i.e., district)
- Applicable to **49%** of stock floor area.

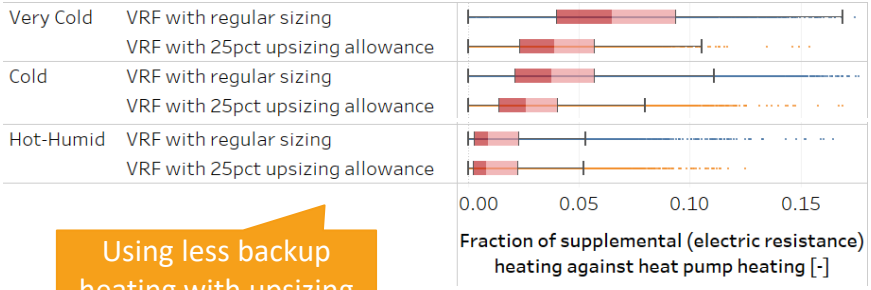


VRF With 25% Upsizing Allowance for Heating

VRF with 25% upsizing vs. baseline:

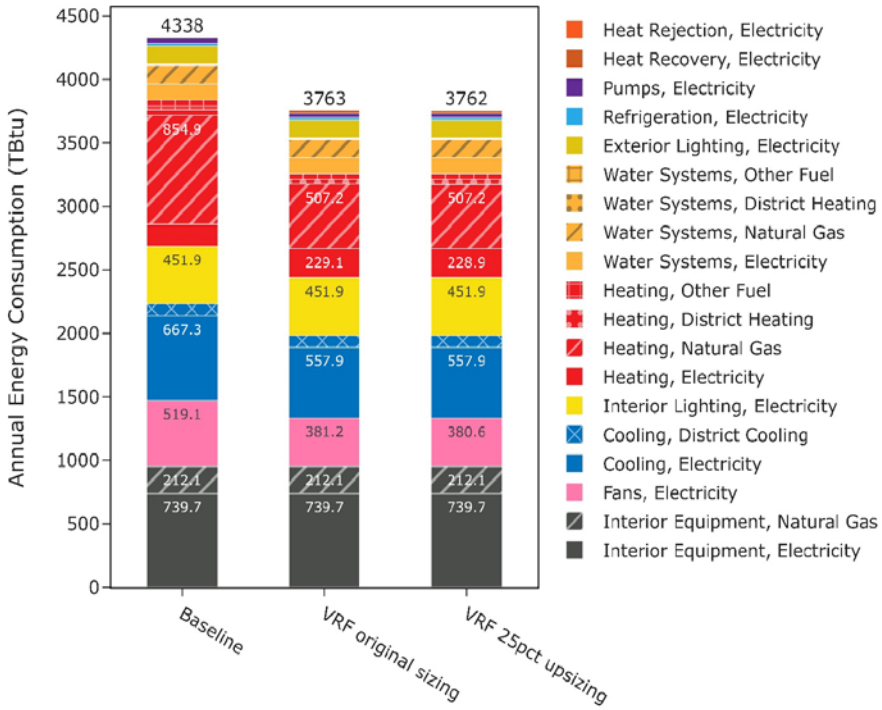
- **41%** stock **heating natural gas** savings (348 TBtu)
- **–31%** stock **heating electricity** savings (–54 TBtu)
- **27%** stock **fan electricity** savings (139 TBtu)
- **16%** stock **cooling electricity** savings (109 TBtu)
- Gas heating savings and electric heating penalty due to electrification
- Fan savings from decoupled ventilation and high-efficiency fans

Fraction Heating Electricity Supplemental

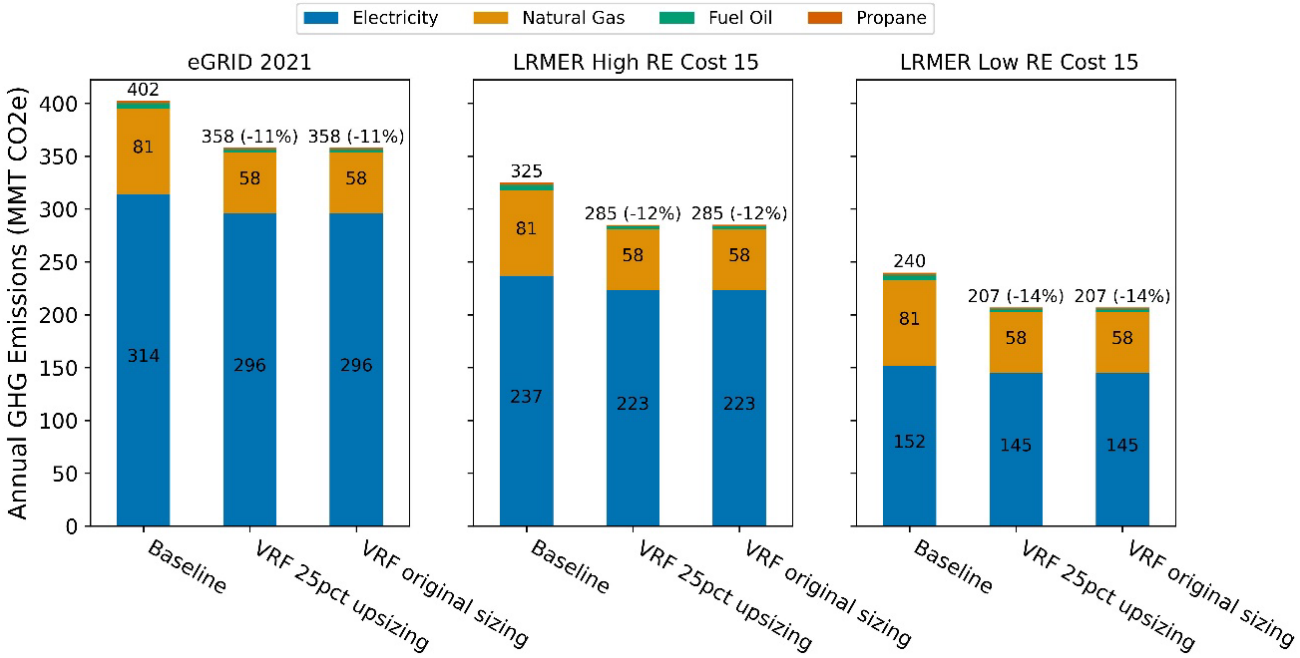


Using less backup heating with upsizing

Stock Site Energy by Fuel and End Use



VRF With 25% Upsizing Allowance for Heating



- Net emissions avoided across all comprehensive grid scenarios and fuel types presented.
- Electricity savings from fans, cooling, and heat/energy recovery savings outweigh heating electricity increase, resulting in net electricity emissions avoided.
- Small difference between upgrade scenarios is due to the combined effect of decreased rated COP and less use of backup heating in the upsizing scenario.

Electricity Grid Scenarios

- eGRID 2021 = Emissions & Generation Resource Integrated Database, year 2021
- LRMER High RE Cost 15 = Cambium Long Run Marginal Emissions Rate, high renewable energy cost, 15 year
- LRMER Low RE Cost 15 = Cambium Long Run Marginal Emissions Rate, low renewable energy cost, 15 year

Electric Cooking Equipment

Electric Cooking Equipment

Measure Concept

- Replace gas-fired cooking equipment with comparable electric equivalents
- Power and internal gain fractions modified; schedules not modified.

Applicability

- Building types with kitchens: restaurants, strip malls, schools, hospitals, large hotels
- Applicable to **38%** of stock floor area
- Data sources: ASHRAE Fundamentals Handbook, Food Service Technology Center (FTSC), PG&E, DOE, KaTom Restaurant Supply, Webstaurant Store, GoFoodservice.

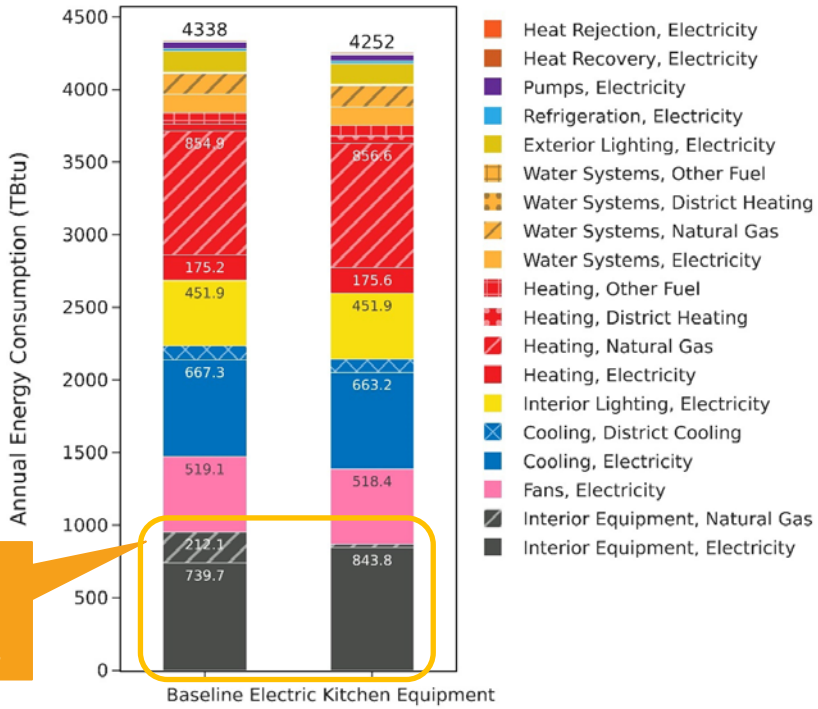
Technology Specifications

Appliance	Existing Gas Equipment Power		New Electric Equipment Power
	Rated Power (Btu/h)	Rated Power (kW)	Rated Power (kW)
Broilers	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

Electric Cooking Equipment

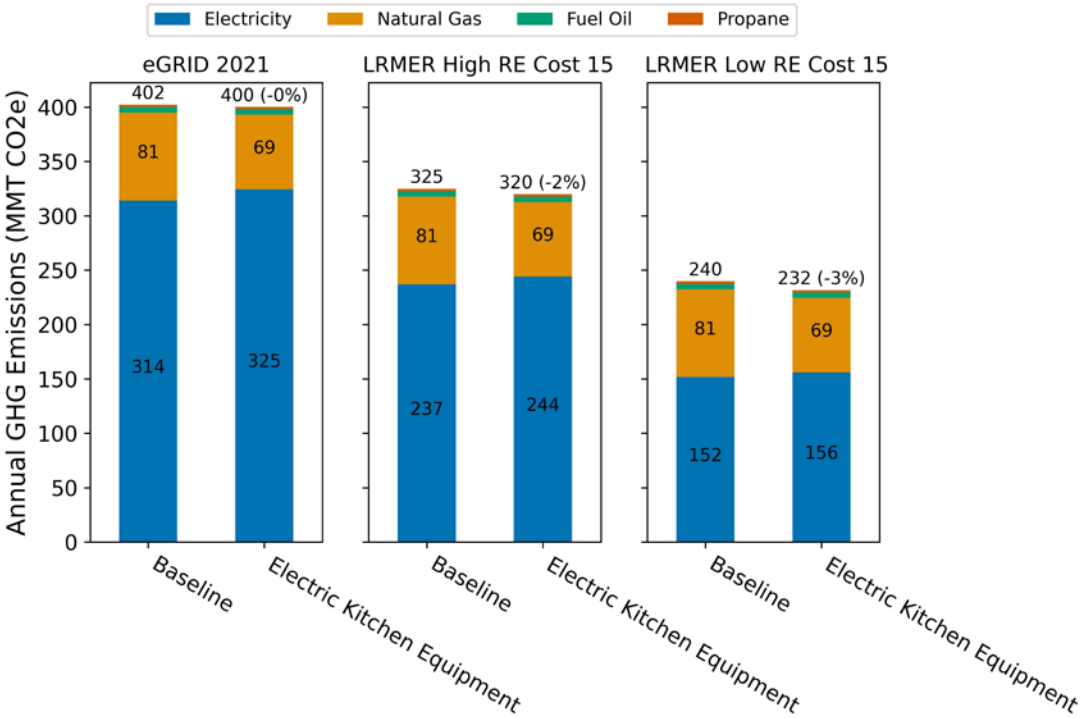
- **88.2%** stock **natural gas interior equipment** savings (187.0 TBtu)
- **–14.1%** stock **electricity interior equipment** savings (–104.1 TBtu)
- **–0.2%** stock **natural gas heating** savings (–1.7 TBtu)
- **0.6%** stock **electricity cooling** savings (4.1 TBtu)
- Minor heating and cooling changes due to changes in internal gains in kitchen spaces.

Stock Site Energy by Fuel and End Use



Gas equipment mostly electrified; remaining use from clothes dryers and other miscellaneous equipment.

Electric Cooking Equipment



- Emissions avoid across all comprehensive grid scenarios presented.
- **15%** reduction in natural gas emissions.
- **2.6-3.5%** increase in electricity emissions from electrifying gas cooking equipment.
- Impact is more substantial when only looking at buildings that have cooking equipment.

Electricity Grid Scenarios

- eGRID 2021 = Emissions & Generation Resource Integrated Database, year 2021
- LRMER High RE Cost 15 = Cambium Long Run Marginal Emissions Rate, high renewable energy cost, 15 year
- LRMER Low RE Cost 15 = Cambium Long Run Marginal Emissions Rate, low renewable energy cost, 15 year

Package 5, Variable-Speed HP-RTU or HP Boilers + DCV + Energy Recovery + Economizer

Package 5, Variable-Speed HP-RTU or HP Boilers + DCV + Energy Recovery + Economizer

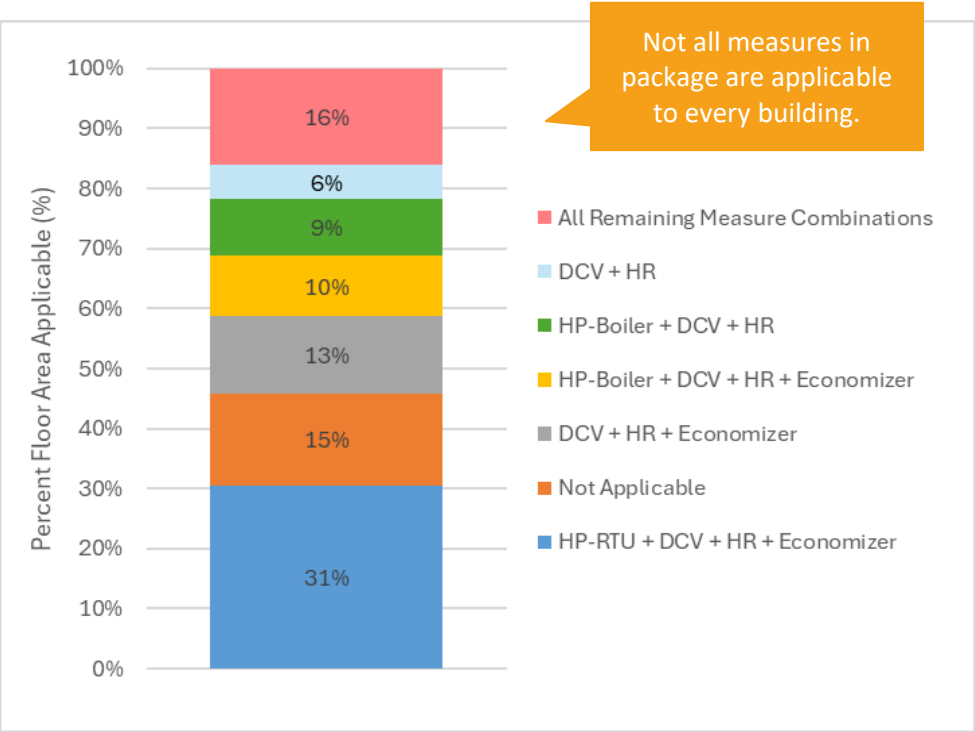
Package Concept:

Combination of five measures from previous and current EUSS releases: HP-RTU or HP-Boiler, plus Demand Control Ventilation, Heat/Energy Recovery, and Economizers

Applicability

- Package 5 is applicable to **85%** of stock for at least one measure.
- Applicable floor area by individual measure:
  - HP-RTU – **33%**
  - HP-Boiler – **29%**
  - DCV – **71%**
  - HR – **78%**
  - Economizers – **57%**

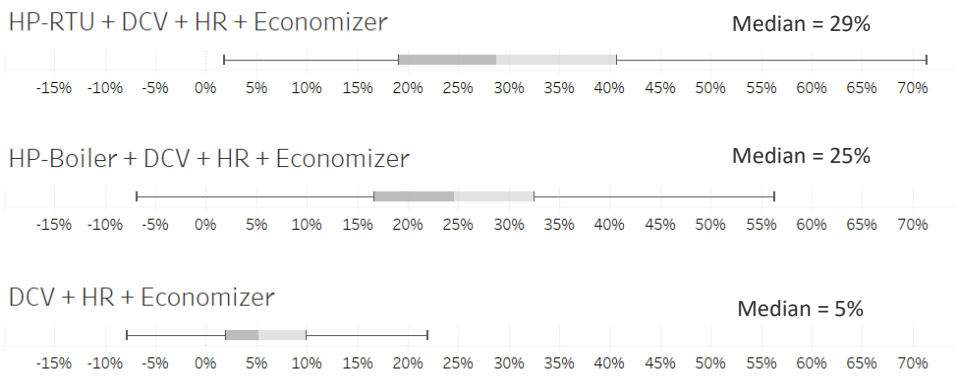
Applicability: % Floor Area per Measure Combination



Package 5, Variable-Speed HP-RTU or HP Boilers + DCV + Energy Recovery + Economizer

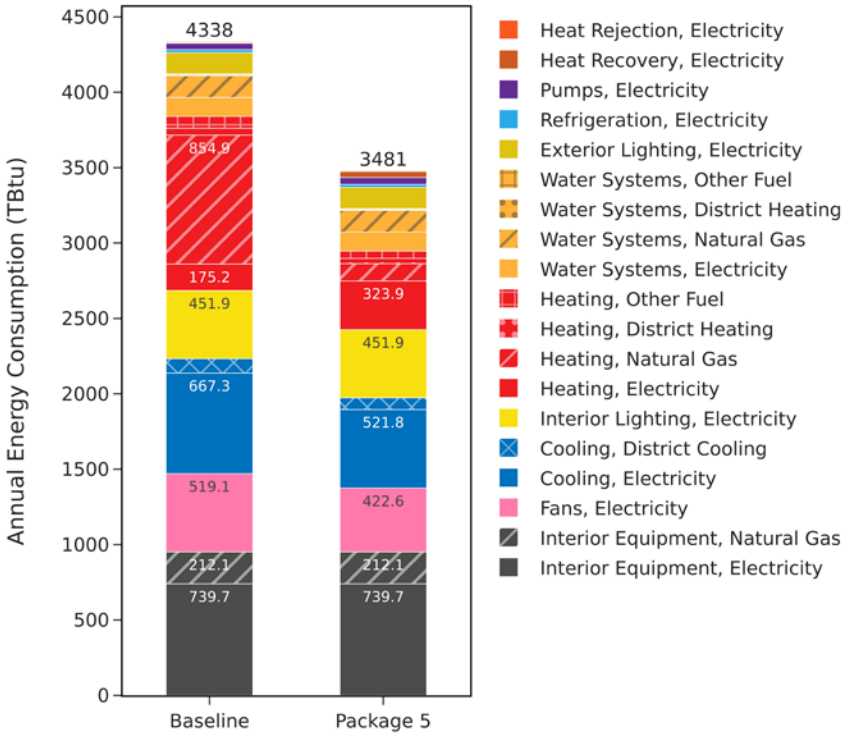
- **87%** stock **heating gas** savings (741 TBtu)
- **–85%** stock **heating electricity** savings (–149 TBtu)
- **22%** stock **cooling electricity** savings (146 TBtu)
- **19%** stock **fan electricity** savings (97 TBtu)

Site % Savings* by Measure Combination

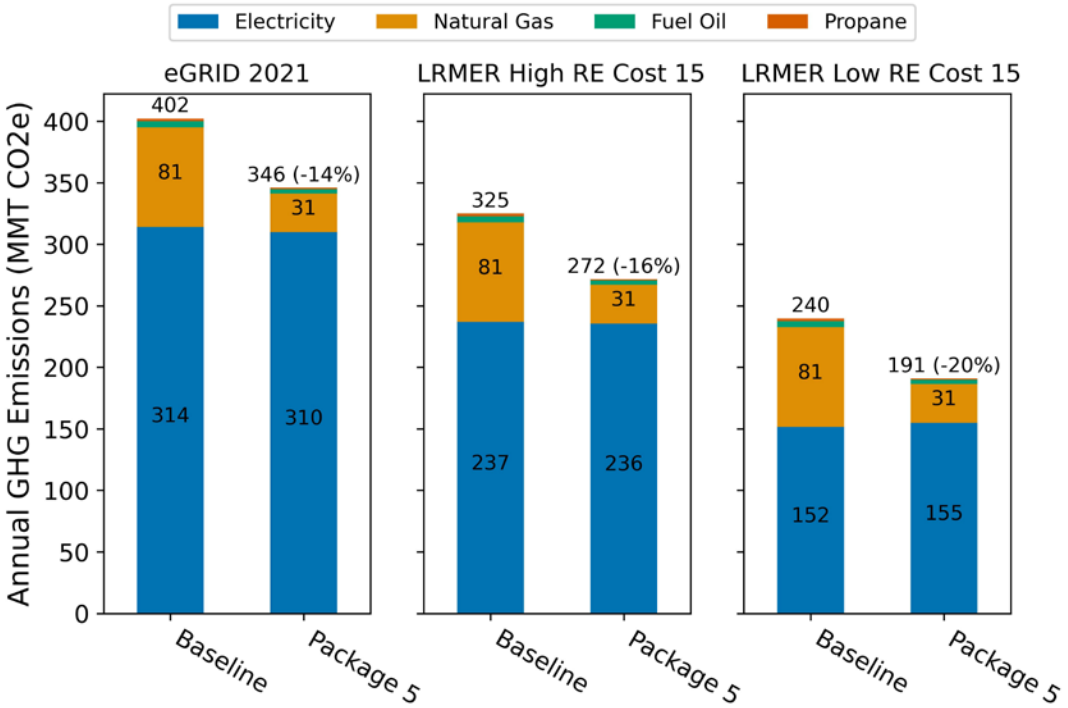


**Note that site energy savings do not necessarily translate proportionally to savings for source energy, operational cost, or avoided greenhouse gas emissions.*

Stock Site Energy by Fuel and End Use



Package 5, Variable-Speed HP-RTU or HP Boilers + DCV + Energy Recovery + Economizer



- **14-20% net emissions avoided** for all grid scenarios presented.
- **62% reduction** in **natural gas** emissions due to electrifying heating systems.
- Additional electricity from electrifying heating is offset by reduced cooling and fan energy.
  - Minimal overall difference in electricity emissions.

Electricity Grid Scenarios

- eGRID 2021 = Emissions & Generation Resource Integrated Database, year 2021
- LRMER High RE Cost 15 = Cambium Long Run Marginal Emissions Rate, high renewable energy cost, 15 year
- LRMER Low RE Cost 15 = Cambium Long Run Marginal Emissions Rate, low renewable energy cost, 15 year

Geothermal Heat Pump Measures

Geothermal Heat Pump Measures

Three geothermal heat pump configurations informed by technical advisory group.

Packaged Water-to-Air GHP

- Retrofit for RTUs and Packaged VAVs
- Includes economizing and DCV
- Applicable to **56%** of floor area
- Performance Data Source: Trane Axiom GWS 10-ton unit.

Console Water-to-Air GHP

- Retrofit for PTACs, residential style systems, baseboards, unit heaters
- Applicable to **11%** of floor area
- Performance Data Source: Trane Axiom GWS 3-ton unit.

Central Hydronic Water-to-Water GHP

- Retrofit for central hydronic systems, e.g,. VAVs with boilers and/or chillers
- Applicable to **13%** of floor area
- Performance Data Source: Carrier 60WG/30WG Series.

Geothermal Heat Pump Measures: Comprehensive GHP Package

Measure Concept

The three GHP measures were run separately, as well as together in a package referred to as the "Comprehensive GHP Package" (Package results are presented here).

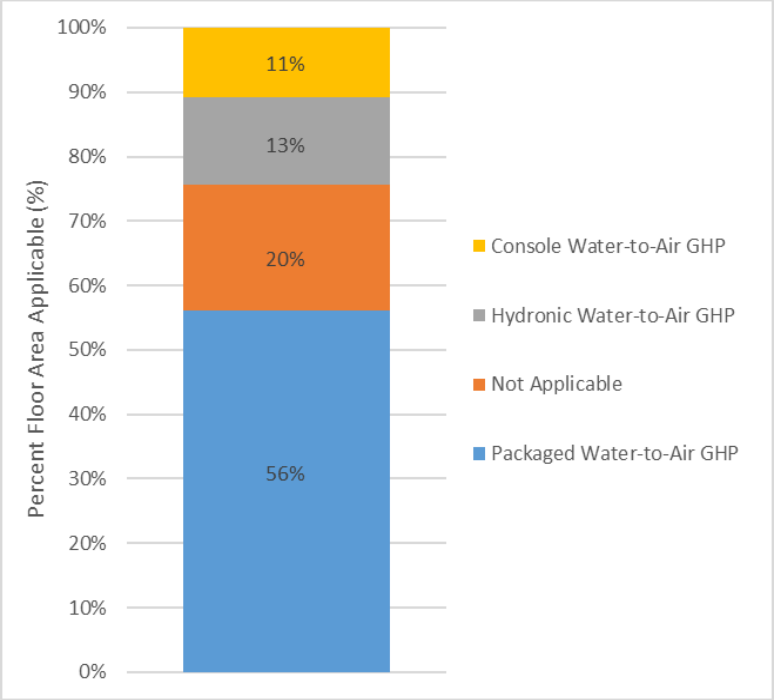
Applicability

- Package is applicable to **80%** of stock floor area.
- Applicable floor area by individual measure:
  - Packaged GHP: 56%
  - Console GHP: 11%
  - Hydronic GHP: 13%.

Ground Heat Exchanger Modeling

- Workflow leverages GHEDesigner Python package for automated ground heat exchanger/borefield sizing based on annual building loads.

Applicability: % Floor Area per Measure

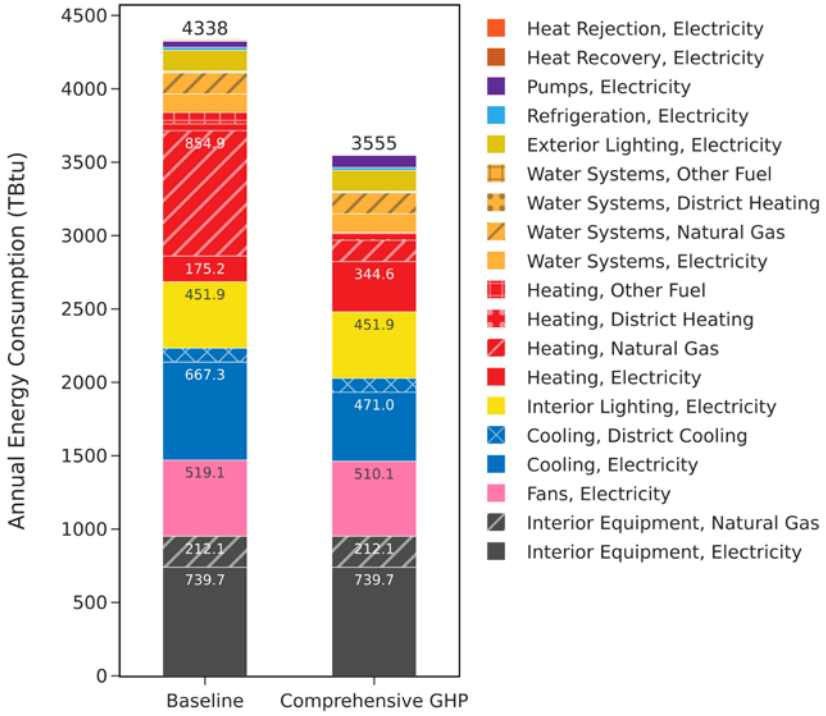


All three GHP measures are mutually exclusive

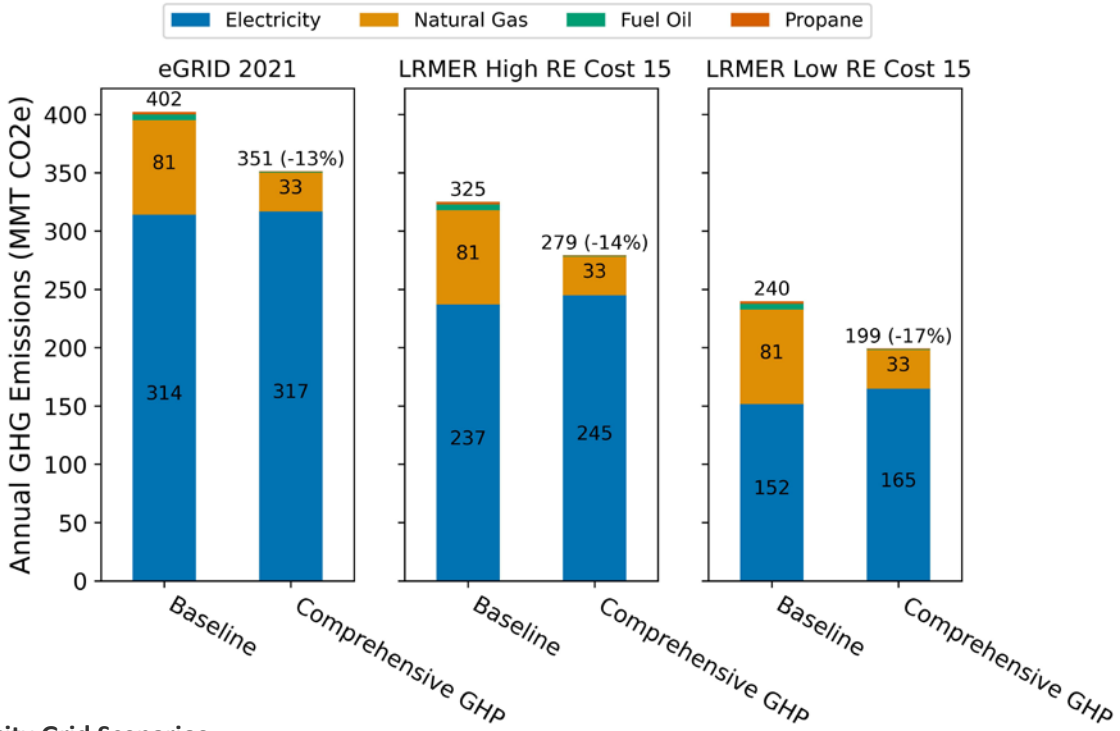
Geothermal Heat Pump Measures

- **83%** stock **heating gas** savings (712 TBtu)
- **–97%** stock **heating electricity** savings (−169 TBtu)
- **29%** stock **cooling electricity** savings (196 TBtu)
- **–92%** stock **pump electricity** savings (−39 TBtu)
- Gas heating savings and electric heating penalty from electrification
- Cooling savings from high ground-source heat pump efficiencies.
- Increased pump energy from adding geothermal hydronic water loops that require pumping.

Stock Site Energy by Fuel and End Use



Geothermal Heat Pump Measures



- **13-17%** net emissions **avoided** across all scenarios presented.
- **59%** natural gas emissions **avoided** due to electrifying **83%** of stock gas heating.
- **1-9%** electricity emissions **induced** across scenarios due to added electric heating.

Electricity Grid Scenarios

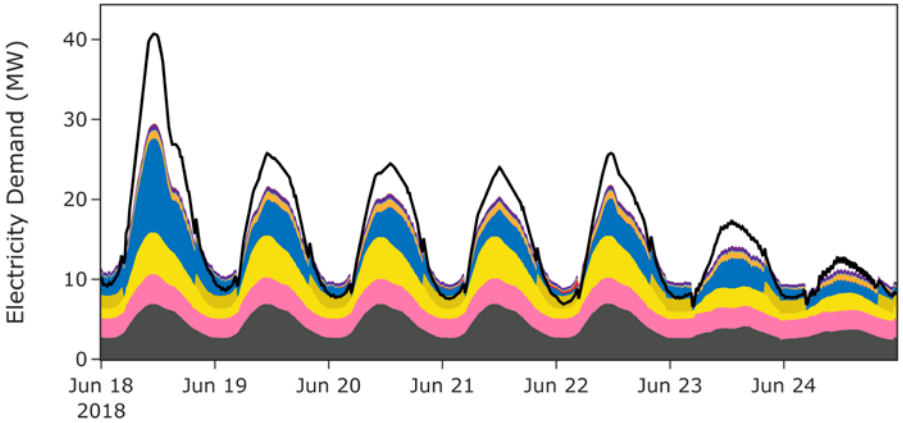
- eGRID 2021 = Emissions & Generation Resource Integrated Database, year 2021
- LRMER High RE Cost 15 = Cambium Long Run Marginal Emissions Rate, high renewable energy cost, 15 year
- LRMER Low RE Cost 15 = Cambium Long Run Marginal Emissions Rate, low renewable energy cost, 15 year

Geothermal Heat Pump Measures

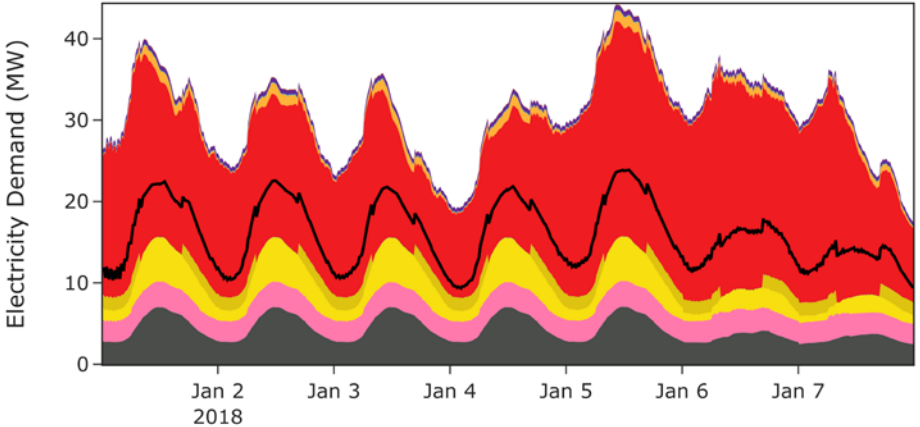
Location: Rochester, NY
Time step: 15 minutes

Scope: Total commercial stock
Fuel: Electricity

Summer Peak



Winter Peak



Baseline Total	heat_recovery	heat_rejection
pumps	refrigeration	water_systems
heating	cooling	exterior_lighting
interior_lighting	fans	interior_equipment

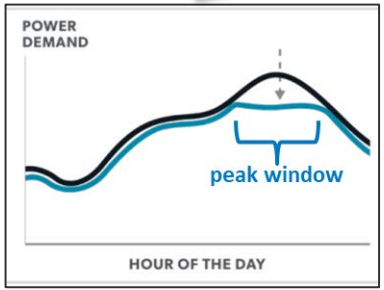
Note that load profiles are **heavily influenced** by assumptions for heat pump sizing routine, lockout temperature, and performance curves.

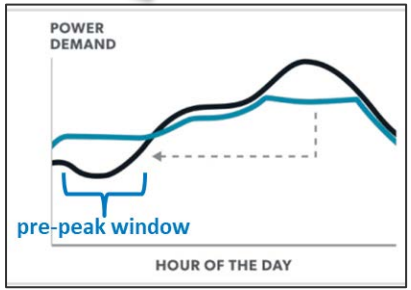
Demand Flexibility Measures

Demand Flexibility Measures

Measure Concept

- Building-level daily peak load reduction
- HVAC thermostat setpoint control
- **Load shedding** and **load shifting.**





Applicability

- Large offices
- Applicable to **~10%** of stock floor area
  - 1/3 electric heating & cooling
  - 2/3 electric cooling only.

Technology Specifications

Assumes perfect prediction of load profile

Create daily dispatch schedule (daily peak window)

Load shed

- Adjust thermostat setpoint by **2°C** in **4-hour (daily) peak** window
- **2-hour rebound control** in post-peak period.

Load shift

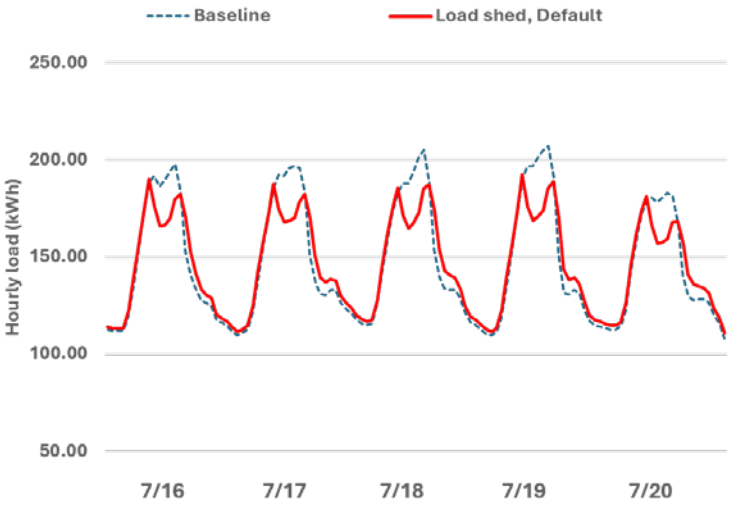
- Adjust thermostat setpoint by **1°C** in (daily) pre-peak period
- **2-hour pre-peak** window.

Demand Flexibility Measures

- **2%–5%** stock **daily peak reduction** with load shed measure.

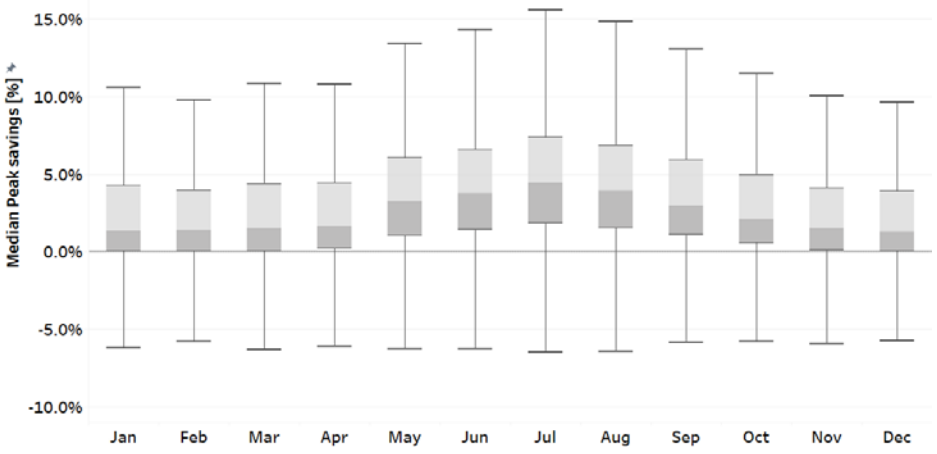
Thermostat control for load shedding

Single Load Profile



Stock Peak Savings

Median daily peak reduction for each month



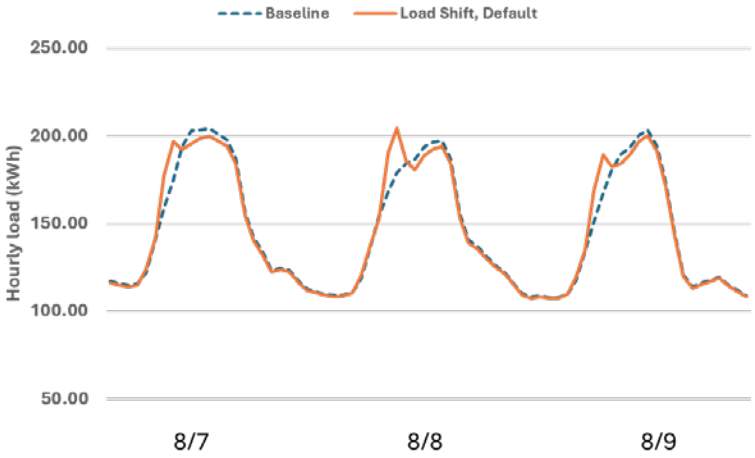
Savings are negative when rebound effect is not successfully diminished

Demand Flexibility Measures

- **0%–1%** stock **daily peak reduction** with load shift measure (pre-cooling only).

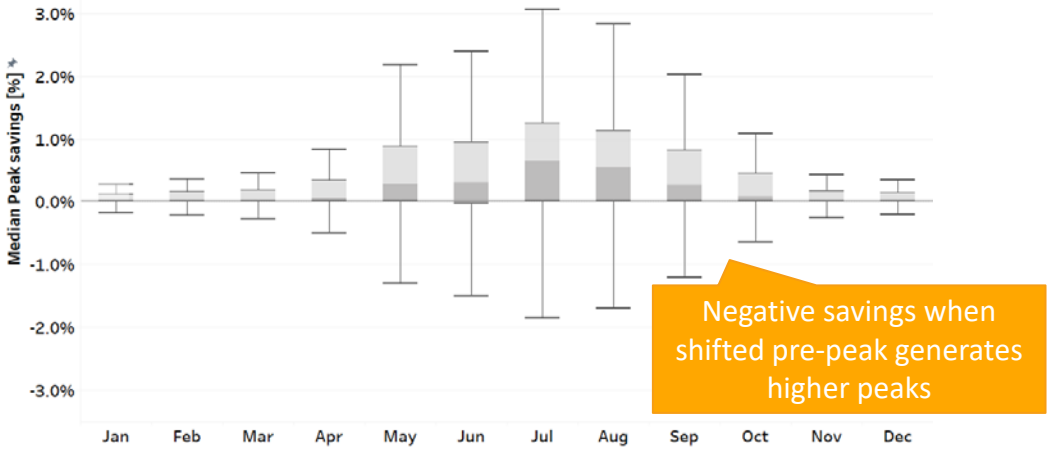
Thermostat control for load shifting

Single Load Profile



Stock Peak Savings

Median building daily peak reduction for each month



Accessing the Data Set

Accessing the Data

	Metadata	Individual Load Profiles	Aggregate Load Profiles	Data Viewer	Full Database
Data Format	.csv and .parquet files	.csv and .parquet files	.csv and .parquet files	Dashboard with .csv exports	Amazon S3 bucket
Time Scale	Annual	15-minute intervals	15-minute intervals	Customizable	Annual or 15-minute intervals
Grouped by	Individual building ID	Individual building ID	Geograhies: climate zone, ISO/RTO region, state	Customizable	Customizable
Fields by	Building input characteristics	-	-	-	Building input characteristics
	Energy consumption	Energy consumption	Energy consumption	Energy consumption	Energy consumption
	Energy savings	Energy savings	Energy savings	Energy savings	Energy savings
	Emissions	-	-	-	Emissions
	Calculated fields	-	-	-	Calculated fields
Accessed via	OEDI	OEDI	OEDI	ComStock.nrel.gov	Scripting languages

OEDI = Open Energy Data Initiative

Field Naming Convention

Prefix or Name	Description	Example
in.	Inputs of building characteristics and geospatial codes	in.window_type
out.	Simulation outputs	out.electricity.refrigeration.energy_consumption
calc.	Calculated values such as totals and % savings	calc.weighted.electricity.cooling.energy_consumption..tbtu
weight	Value for scaling single model results to national scale	4.8960474
bldg_id	Unique ID of the building model	3324
upgrade	Unique ID number for upgrade	5
model_count	Number of models aggregated (time-series files)	5334
applicability	Upgrade names	FALSE
Second Level		
out.[fuel type]	Fuel type: electricity, natural gas, etc.	out.natural_gas.water_systems.energy_consumption
out.emissions	Emission values	out.emissions.electricity.egrid..co2e_kg
out.params	Model parameters and summary statistics	out.params.dx_cooling_average_cop..cop
out.qoi	Quantities of interest such as peak demand	out.qoi.maximum_daily_use_summer_kw..kw
out.site_energy	Total of all end uses, site energy	out.site_energy.total.energy_consumption
Third Level		
out.[fuel type].[end use]	End uses: heating, cooling, lighting, water systems, etc.	out.electricity.heating.energy_consumption
Units		
..foo	".." denotes the start of the unit name	..kWh_per_ft2

Data dictionary available at OEDI

Open Energy Data Initiative (OEDI) Folder Structure

OEDI AWS S3 Explorer for the Open Energy Data Initiative

oedi-data-lake / nrel-pds-building-stock / end-use-load-profiles-for-us-building-stock / 2024 / comstock_amy2018_release_1

Show 50 entries

Object	Timestamp	Size
building_energy_models/		
comparison_plots/		
metadata/		
metadata_and_annual_results/		
timeseries_aggregates/		
timeseries_individual_buildings/		
weather/		
Upgrade Measure Documentation Links.txt	2024-03-29 12:51:38	143 B
Webinar Links.txt	2024-03-29 12:51:51	189 B
batch_state.json	2024-03-22 15:52:56	57 B
data_dictionary.tsv	2024-03-29 10:23:07	174.9 kB
enumeration_dictionary.tsv	2024-03-29 10:23:06	35.6 kB
measure_name_crosswalk.csv	2024-03-29 12:50:01	5.2 kB
upgrades_lookup.json	2024-03-29 10:36:07	1.5 kB

Showing 1 to 14 of 14 entries

Metadata files with annual usage, building characteristics, equipment size and performance, etc.

Time-series data by fuel type and end use; various pre-aggregations

CSV **weather files**

Dictionary of available **data fields with definitions**

Dictionary of **upgrade IDs and names**

Access at: OEDI

Example Metadata File

Building ID

County

Building Type

Building Area (unweighted)

Annual Electricity Peak kW (unweighted)

Annual Natural Gas Consumption (unweighted)

	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AP	AQ	AR	
1	in.building_id	in.window_type	in.building_subtype	in.county	in.comstock_building_type	in.rotation.degrees	in.number_of_stories	in.sqft	in.hvac_system_type	in.wall_construction_type	in.weekday_operating_hours..hr	in.weekday_opening_time..hr	in.weekend_operating_hours..hr	in.weekend_opening_time..hr	out.electricity.total.peak_demand..kW	out.district_cooling.cooling.energy_consumption	out.district_heating.heating.energy_consumption	out.natural_gas.total.energy_consumption
2	55	Double - No LowE	NA	G0100030	Outpatient	225	3	37500	PSZ-AC with ele	Mass	8	8.75	8.75	6.75	288.54417	0	0	41180.55556
3	324	Single - No LowE -	NA	G0101250	Hospital	270	3	350000	VAV air-cooled	SteelFramed	8.5	8.5	12	4.75	2537.623	0	0	2049280.556
4	457	Double - LowE - Cl	NA	G0100830	Hospital	90	2	150000	VAV air-cooled	SteelFramed	8.75	8	14.75	7.75	1112.82938	0	966591.667	312955.5556
5	496	Double - No LowE	NA	G0100350	Hospital	270	2	150000	VAV chiller with	Mass	13.75	6.25	6	11.5	1016.74873	0	0	1320636.111
6	758	Double - No LowE	NA	G0100730	Outpatient	0	4	75000	PSZ-AC with gas	Mass	7.5	8.25	11.25	10.25	412.52324	0	0	176772.2222
7	766	Double - LowE - Ti	NA	G0100550	Hospital	0	7	37500	PVAV with gas b	SteelFramed	8.75	7	11	5.75	292.54247	0	0	426252.7778
8	1122	Single - No LowE -	NA	G0100950	Hospital	315	3	150000	PVAV with gas b	WoodFramed	9.5	7	6	11.5	1264.01005	0	0	3154086.111
9	1934	Double - LowE - Ti	NA	G0100730	Hospital	270	5	1000000	PVAV with gas b	SteelFramed	9	7.5	7.25	9.75	6813.14901	0	0	6029661.111
10	2357	Double - LowE - Cl	NA	G0100730	Outpatient	180	2	75000	PSZ-AC with gas	WoodFramed	9.5	6.75	10.75	4.75	374.63398	0	0	179880.5556
11	3324	Single - No LowE -	NA	G0100950	Hospital	270	3	350000	VAV chiller with	Mass	9	7.5	8.25	7	2152.99659	0	0	2584791.667
12	3640	Double - LowE - Cl	NA	G0100170	Hospital	90	3	350000	VAV air-cooled	SteelFramed	9.75	7	12	5.5	2544.36643	0	847533.333	334913.8889
13	3801	Single - No LowE -	NA	G0100730	Outpatient	180	3	75000	PSZ-AC with gas	Mass	8.5	7.5	10.75	11	489.49215	0	0	170322.2222
14	5764	Single - No LowE -	NA	G0200500	Hospital	270	1	75000	VAV chiller with	WoodFramed	9	8	10	6.75	329.3614	0	0	2559697.222
15	6058	Double - No LowE	NA	G0400190	Outpatient	45	1	37500	PSZ-AC with gas	SteelFramed	8.25	5.5	8.75	9.25	294.87621	0	0	65736.11111
16	6194	Single - No LowE -	NA	G0400130	Outpatient	225	1	75000	PSZ-AC with ele	SteelFramed	7.75	6.5	11.25	6.75	600.52446	0	0	83033.33333
17	6447	Double - No LowE	NA	G0400190	Outpatient	180	2	17500	PSZ-AC with ele	WoodFramed	6.5	6.5	10.5	8.5	99.54627	0	0	18208.33333
18	6752	Double - LowE - Ti	NA	G0400130	Outpatient	180	1	37500	PSZ-AC with ele	SteelFramed	7	7	17.5	5.25	209.44043	0	0	42166.66667
19	7153	Double - LowE - Cl	NA	G0400130	Outpatient	315	1	37500	PSZ-AC with ele	SteelFramed	7.75	9.5	7.25	10	310.28772	0	0	40255.55556
20	7500	Single - No LowE -	NA	G0400190	Outpatient	225	1	37500	PSZ-AC with ele	Mass	7.25	8.75	15.5	4.5	331.52824	0	0	41991.66667
21	7516	Double - No LowE	NA	G0400130	Outpatient	0	1	37500	PSZ-AC with ele	Mass	7	6.5	10.75	9.75	283.39981	0	0	40002.77778
22	7535	Double - No LowE	NA	G0400190	Outpatient	0	1	17500	PSZ-AC with gas	SteelFramed	9	8.5	10	10.75	122.88107	0	0	32330.55556
23	7662	Single - No LowE -	NA	G0400130	Outpatient	135	2	75000	PSZ-AC with ele	SteelFramed	10.25	6.5	11	12	592.7709	0	0	91941.66667

Example Time-Series File

Building ID

Timestamp

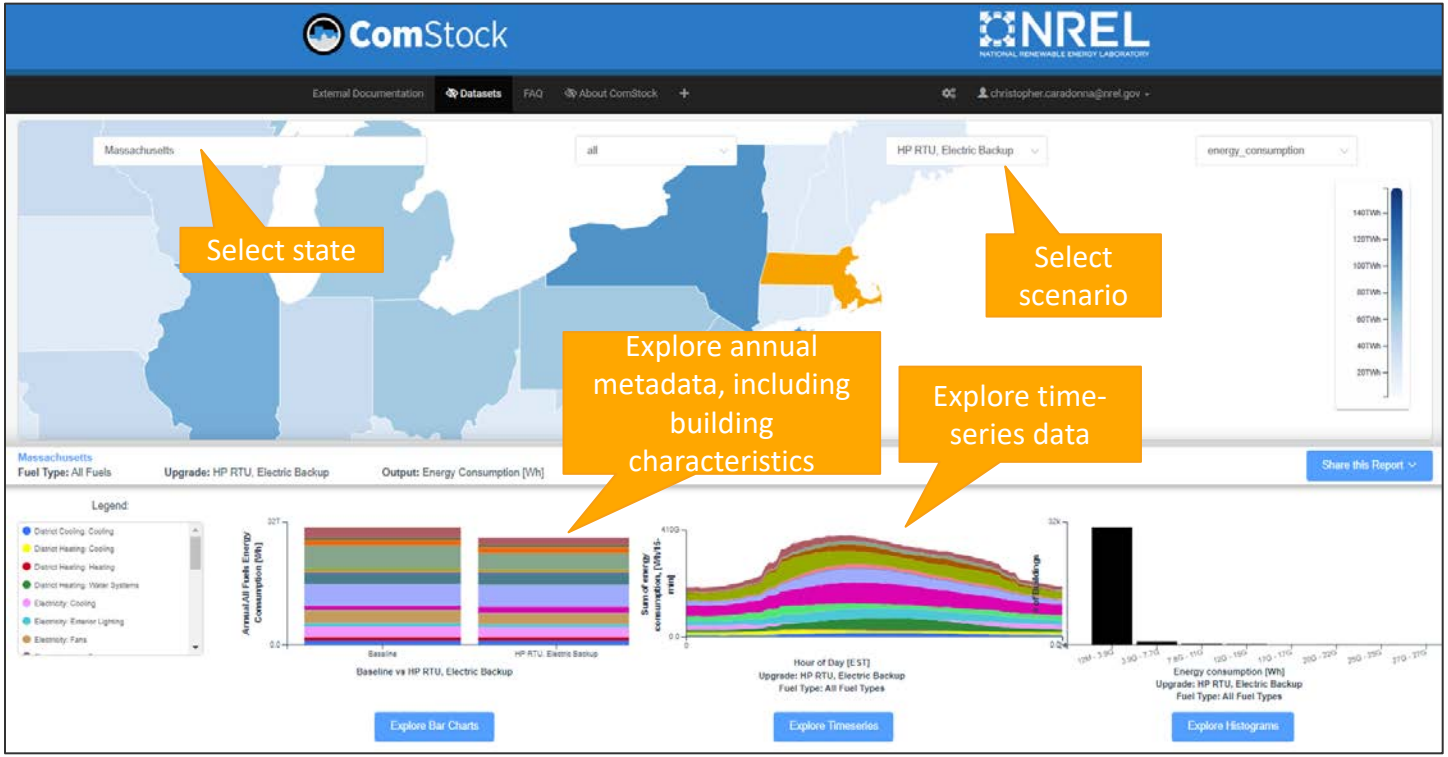
Exterior Lighting Consumption (kWh)

Interior Lighting Consumption (kWh)

Gas Heating Consumption (kWh)

	B	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1 bldg_id	timestamp	out.electricity.cooling.energy_consumption	out.electricity.exterior_lighting.energy_consumption	out.electricity.fans.energy_consumption	out.electricity.heat_recovery.energy_consumption	out.electricity.heat_rejection.energy_consumption	out.electricity.heating.energy_consumption	out.electricity.interior_equipment.energy_consumption	out.electricity.interior_lighting.energy_consumption	out.electricity.pumps.energy_consumption	out.electricity.refrigeration.energy_consumption	out.electricity.water_systems.energy_consumption	out.natural_gas.heating.energy_consumption	out.natural_gas.interior_equipment.energy_consumption	out.natural_gas.water_systems.energy_consumption
2 5324	1/1/2018 0:15	0	1.2107	3.4499	0	0	0	2.3114	0.3319	0.0003	0	0	0	0	0.278477731
3 5324	1/1/2018 0:30	0	1.2107	3.4499	0	0	0	2.1577	0.2885	0.0003	0	0	0	0	0.763094899
4 5324	1/1/2018 0:45	0	1.2107	3.4499	0	0	0	1.8502	0.2017	0.0003	0	0	0	0	0.678523028
5 5324	1/1/2018 1:00	0	1.2107	3.4499	0	0	0	1.6965	0.1583	0.0003	0	0	0	0	0.262133379
6 5324	1/1/2018 1:15	0	1.2107	3.4499	0	0	0	1.2485	0.1461	0.0003	0	0	0	0	0.801860046
7 5324	1/1/2018 1:30	0	1.2107	3.4499	0	0	0	1.0245	0.1399	0.0003	0	0	0	0	0.608005027
8 5324	1/1/2018 1:45	0	1.2107	3.4499	0	0	0	0.5764	0.1277	0.0003	0	0	0	0	0.242852543
9 5324	1/1/2018 2:00	0	1.2107	3.4499	0	0	0	0.3524	0.1216	0.0003	0	0	0	0	0.834873996
10 5324	1/1/2018 2:15	0	1.2107	3.4499	0	0	0	0.5835	0.0811	0.0003	0	0	0	0	0.524560196
11 5324	1/1/2018 2:30	0	1.2107	3.4499	0	0	0	0.6991	0.0608	0.0003	0	0	0	0	0.298359756
12 5324	1/1/2018 2:45	0	1.2107	3.4499	0	0	0	0.9302	0.0203	0	0	0	0	0	0.420222982
13 5324	1/1/2018 3:00	0	1.2107	3.4499	0	0	0	1.0457	0	0	0	0	0	0	0.053723496
14 5324	1/1/2018 3:15	0	1.2107	3.4499	0	0	0	1.0449	0.0026	0	0	0	0	0	0
15 5324	1/1/2018 3:30	0	1.2107	3.4499	0	0	0	1.0445	0.0039	0	0	0	0	0	0
16 5324	1/1/2018 3:45	0	1.2107	3.4499	0	0	0	1.0437	0.0065	0	0	0	0	0	0
17 5324	1/1/2018 4:00	0	1.2107	3.4499	0	0	0	1.0433	0.0078	0	0	0	0	0	0
18 5324	1/1/2018 4:15	0	1.2107	3.4499	0	0	0	1.0424	0.0104	0	0	0	0.438	0	0
19 5324	1/1/2018 4:30	0	1.2107	3.4499	0	0	0	1.042	0.0117	0	0	0	0.3853	0	0
20 5324	1/1/2018 4:45	0	1.2107	3.4499	0	0	0	1.0412	0.0143	0	0	0	0.2948	0	0
21 5324	1/1/2018 5:00	0	1.2107	3.4499	0	0	0	1.0408	0.0156	0	0	0	0.16	0	0
22 5324	1/1/2018 5:15	0	1.2107	3.4499	0	0	0	1.04	0.0183	0	0	0	0.1943	0	0
23 5324	1/1/2018 5:30	0	1.2107	3.4499	0	0	0	1.0396	0.0196	0	0	0	0.2245	0	0
24 5324	1/1/2018 5:45	0	1.2107	3.4499	0	0	0	1.039	0.0215	0	0	0	0.2503	0	0.474015352
25 5324	1/1/2018 6:00	0	1.2107	3.4499	0	0	0	0.9423	0.0579	0	0	0	0.278	0	0

ComStock Data Viewer

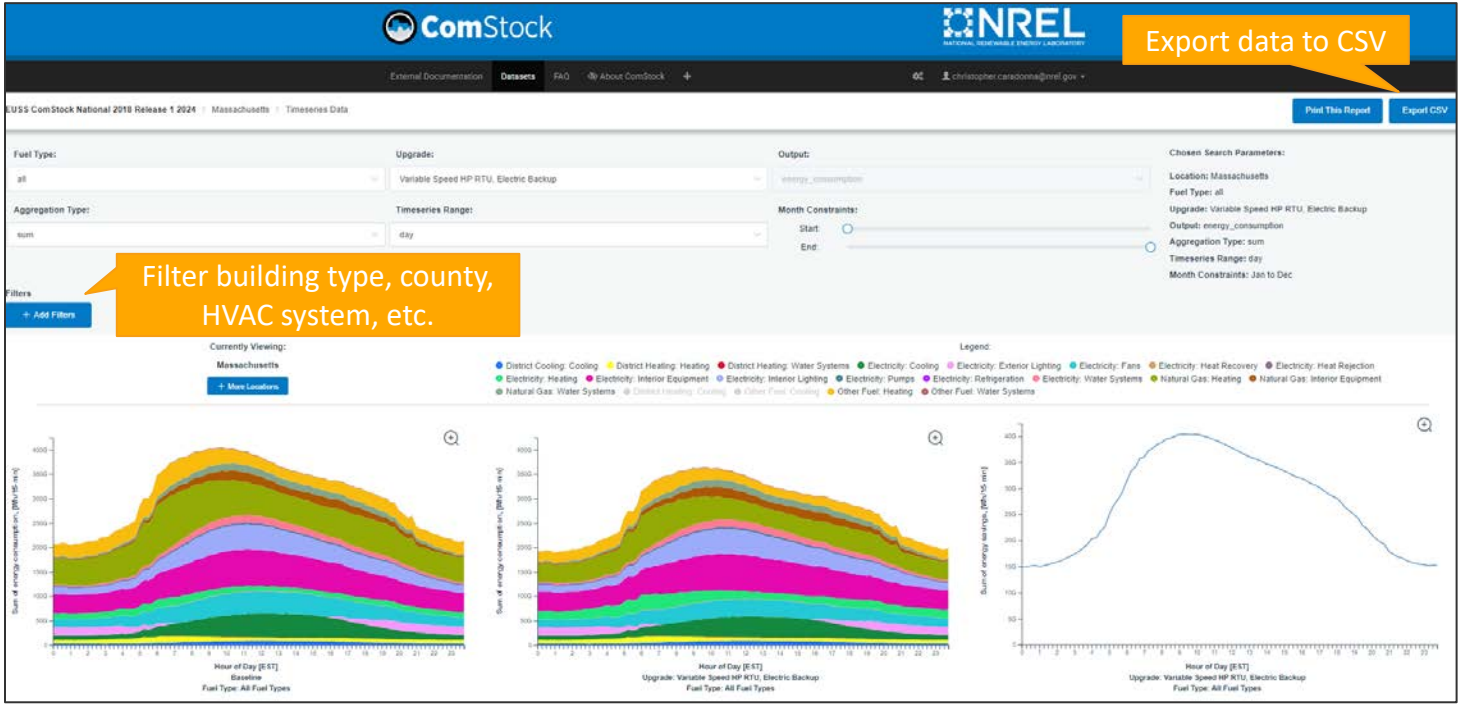


- Visualize data
- Export to csv
- Custom timeseries aggregations

Requires free account

Access at: ComStock.nrel.gov

ComStock Data Viewer



- Visualize data
- Export to csv
- Custom timeseries aggregations

Requires free account

Access at: ComStock.nrel.gov

A Few Reminders

- All time stamps are time-period-ending and are in EST.
- Annual metadata files provide weighting factors for national scaling. Columns with “weighted” in the title already have this factor applied.
- Check your sample sizes on custom aggregations—too few samples can increase uncertainty.
- All “out.” columns without units denoted are in kWh.
  (This is driven by current limitations with the data viewer.)

Next Steps

Commercial EUSS FY25

Potential List for Next Release; Expected November 2024

Measure Name	Description
HP-RTU, Electric Backup, Standard Performance	Replaces gas and electric resistance RTUs with standard efficiency HP-RTUs.
Ideal Thermal Loads	Provides raw thermal loads in time series profile format.
25% Upsizing for HP-RTU	Size HP-RTU 25% beyond design cooling load as needed to reduce backup heating.
HP-RTU Lockout Temperature Variation	Increases the lockout temperature of HP-RTU measure to 10°F (default=0°F) to understand impact.
HP-RTU, Cold Climate HP-RTU Challenge	Replace gas and electric resistance RTUs with HP-RTUs meeting the performance specification of the cold climate HP-RTU challenge.
Package 1: HP-RTU Standard Performance + Lighting	Package combines standard performance HP-RTU and LED lighting.
Demand Flexibility Measures	Adding new control types (e.g. lighting) as well as several new optimization types (e.g. greenhouse gas emissions, grid peak, etc.). Expand scope beyond large offices.

Email us with measure/package requests for future releases: **comstock@nrel.gov**

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[1] Gagnon, Pieter. n.d. "Cambium | Energy Analysis | NREL." National Renewable Energy Laboratory. https://www.nrel.gov/analysis/cambium.html.

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[3] Vijayakumar, G. et al. 2022. "ANSI/RESNET/ICC 301-2022 - Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index." Oceanside, CA, 2022.