End-Use Savings Shapes

Public Data Set Release: Commercial 2024 Release 1

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NREL Webinar

April 25, 2024
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
A lack of credible and relevant information results in confusion and inaction by cities, states, utilities, and other major stakeholders.

Problem Statement

Will electrification of buildings...
- Reduce carbon emissions in my city?
- Be feasible in my building stock?
- Overload the grid?
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.
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.
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

Building stock characteristics database

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

Physics-based computer modeling

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

High-performance computing

- Simulate models.
- Process and publish data.
- Apply scaling factors.
What Does ComStock Model?

All Buildings in the Commercial Buildings Energy Consumption Survey (CBECS)

- Building Type
  - Other (not modeled in ComStock)
  - Retail strip mall
  - Hospital
  - Large office
  - Full service restaurant
  - Medium office
  - Warehouse
  - Primary school
  - Retail standalone
  - Large hotel
  - Small office
  - Secondary school
  - Outpatient
  - Quick service restaurant
  - Small hotel

- Annual Site Energy Consumption (TBtu)

- Not in ComStock

- Building Type
  - College/university
  - Religious worship
  - Other
  - Mixed-use office
  - Grocery store/food market
  - Nursing home/assisted living
  - Recreation
  - Laboratory
  - Entertainment/culture
  - Vehicle service/repair shop
  - Other public assembly
  - Library
  - Vehicle storage/maintenance
  - Dormitory/fraternity/sorority
  - Other service
  - Refrigerated warehouse
  - Social/meeting
  - Convenience store
  - Enclosed mall
  - Other*

* Includes other public order and safety, convenience store with gas station, other classroom education, vacant, fire station/police station, courthouse/probate 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 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
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

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.

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

On-Site Combustion Fuels

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

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>147.3 lb/mmbtu (228.0 kg/MWh)</td>
</tr>
<tr>
<td>Propane</td>
<td>177.8 lb/mmbtu (182.3 kg/MWh)</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>195.9 lb/mmbtu (303.2 kg/MWh)</td>
</tr>
</tbody>
</table>

* 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
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

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

These are included in the new data set, but not discussed in this presentation.
<table>
<thead>
<tr>
<th>Measure Name</th>
<th>Description</th>
<th>% of Stock Floor Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Speed Heat Pump Rooftop Unit (HP-RTU), Electric Backup, Energy</td>
<td>Replace gas furnace and electric resistance RTUs with variable-speed HP-RTU with electric backup and integrated heat or energy recovery.</td>
<td>33%</td>
</tr>
<tr>
<td>Recovery (ER)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Rooftop Unit (RTU) Controls</td>
<td>Retrofits existing single-zone constant air volume RTUs to include variable-speed fan, economizer, and demand control ventilation.</td>
<td>39%</td>
</tr>
<tr>
<td>Unoccupied Air Handling Unit (AHU) Control</td>
<td>Aligns outdoor air and fan operation to occupancy schedules for existing AHUs.</td>
<td>45%</td>
</tr>
<tr>
<td>Air Side Economizers for AHUs</td>
<td>Adds air-side economizers to existing AHUs.</td>
<td>66%</td>
</tr>
<tr>
<td>VRF With 25% Upsizing Allowance</td>
<td>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.</td>
<td>49%</td>
</tr>
<tr>
<td>Electric Cooking Equipment</td>
<td>Replaces primary gas commercial cooking equipment with similar electric alternatives.</td>
<td>38%</td>
</tr>
<tr>
<td>Package 5, Variable Speed HP RTU or HP Boilers + DCV + Energy Recovery +</td>
<td>Combines several HVAC electrification and efficiency measures: variable-speed HP-RTU or HP boiler with demand control ventilation, energy/heat recovery, and economizers.</td>
<td>85%</td>
</tr>
<tr>
<td>Economizer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### New EUSS 2024 Release 1 Measures (cont’d)

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

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

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.

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.
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.

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

Adding H/ER reduces electric heating and cooling
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
- LMER High RE Cost 15 = Cambium Long Run Marginal Emissions Rate, high renewable energy cost, 15 year
- LMER 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
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

Heat/energy recovery reduces electric demand

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

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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.
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.

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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.

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.

Measure transitions buildings following scheme 1 or 2 to scheme 3
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.
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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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.
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%.

**Electricity Grid Scenarios**
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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.

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**Upgrade applicability**
- Applicable
- Not applicable: large exhaust/ventilation
- Not applicable: floor area > 200,000 sqft
- Not applicable: Central Multi-zone VAV RTU
- Not applicable: Central Single-zone RTU
- Not applicable: DOAS+Zone terminal equipment
- Not applicable: Residential forced air
- Not applicable: Zone terminal equipment
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**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>VRF with regular sizing</th>
<th>VRF with 25% upsizing allowance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Cold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot-Humid</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Using less backup heating with upsizing
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.

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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

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Existing Gas Equipment Power</th>
<th>New Electric Equipment Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rated Power (Btu/h)</td>
<td>Rated Power (kW)</td>
</tr>
<tr>
<td>Broilers</td>
<td>96,000</td>
<td>28.1</td>
</tr>
<tr>
<td>Griddles</td>
<td>90,000</td>
<td>26.4</td>
</tr>
<tr>
<td>Fryers</td>
<td>80,000</td>
<td>23.4</td>
</tr>
<tr>
<td>Ovens</td>
<td>44,000</td>
<td>12.9</td>
</tr>
<tr>
<td>Ranges</td>
<td>145,000</td>
<td>42.5</td>
</tr>
<tr>
<td>Steamers</td>
<td>200,000</td>
<td>58.6</td>
</tr>
</tbody>
</table>
• **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.

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
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- 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%**
• 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)

*Note that site energy savings do not necessarily translate proportionally to savings for source energy, operational cost, or avoided greenhouse gas emissions.*
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.
Geothermal Heat Pump Measures
Three geothermal heat pump configurations informed by technical advisory group.

<table>
<thead>
<tr>
<th>Packaged Water-to-Air GHP</th>
<th>Console Water-to-Air GHP</th>
<th>Central Hydronic Water-to-Water GHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Retrofit for RTUs and Packaged VAVs</td>
<td>• Retrofit for PTACs, residential style systems, baseboards, unit heaters</td>
<td>• Retrofit for central hydronic systems, e.g., VAVs with boilers and/or chillers</td>
</tr>
<tr>
<td>• Includes economizing and DCV</td>
<td>• Applicable to 11% of floor area</td>
<td>• Applicable to 13% of floor area</td>
</tr>
<tr>
<td>• Applicable to 56% of floor area</td>
<td>• Performance Data Source: Trane Axiom GWS 3-ton unit.</td>
<td>• Performance Data Source: Carrier 60WG/30WG Series.</td>
</tr>
</tbody>
</table>

Performance Data Source: Trane Axiom GWS 10-ton unit.
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.

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

![Graph showing energy consumption by fuel and end use.](image)
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

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

Thermostat control for load shedding

**Single Load Profile**

- Baseline
- Load shed, Default

**Stock Peak Savings**

Median daily peak reduction for each month

Savings are negative when rebound effect is not successfully diminished

- 2%–5% stock daily peak reduction with load shed measure.
Demand Flexibility Measures

Thermostat control for load shifting

Single Load Profile

Stock Peak Savings
Median building daily peak reduction for each month

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

Negative savings when shifted pre-peak generates higher peaks.
Accessing the Data Set
# Accessing the Data

<table>
<thead>
<tr>
<th>Metadata</th>
<th>Individual Load Profiles</th>
<th>Aggregate Load Profiles</th>
<th>Data Viewer</th>
<th>Full Database</th>
</tr>
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<tbody>
<tr>
<td><strong>Data Format</strong></td>
<td>.csv and .parquet files</td>
<td>.csv and .parquet files</td>
<td>.csv and .parquet files</td>
<td>Dashboard with .csv exports</td>
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<td><strong>Grouped by</strong></td>
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<td>Individual building ID</td>
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<td>ComStock.nrel.gov</td>
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</table>

OEDI = Open Energy Data Initiative
# Field Naming Convention

<table>
<thead>
<tr>
<th>Prefix or Name</th>
<th>Description</th>
<th>Example</th>
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<tbody>
<tr>
<td>in.</td>
<td>Inputs of building characteristics and geospatial codes</td>
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<td>out.</td>
<td>Simulation outputs</td>
<td>out.electricity.refrigeration.energy_consumption</td>
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<td>calc.</td>
<td>Calculated values such as totals and % savings</td>
<td>calc.weighted.electricity.cooling.energy_consumption..tbtu</td>
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<td>Value for scaling single model results to national scale</td>
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<td>Unique ID of the building model</td>
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<td>Unique ID number for upgrade</td>
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<td>Number of models aggregated (time-series files)</td>
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<td>applicability</td>
<td>Upgrade names</td>
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### 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](https://www.oedi.com/)
Open Energy Data Initiative (OEDI) Folder Structure

Access at: OEDI

- **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**
Example Metadata File

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<th>Building Area (unweighted)</th>
<th>Annual Electricity Peak kW (unweighted)</th>
<th>Annual Natural Gas Consumption (unweighted)</th>
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</table>
ComStock Data Viewer

Access at: ComStock.nrel.gov

- Visualize data
- Export to csv
- Custom timeseries aggregations

Requires free account
ComStock Data Viewer

Export data to CSV

- Visualize data
- Export to csv
- Custom timeseries aggregations

Access at: ComStock.nrel.gov

Filter building type, county, HVAC system, etc.
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
Potential List for Next Release; Expected November 2024

<table>
<thead>
<tr>
<th>Measure Name</th>
<th>Description</th>
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<tbody>
<tr>
<td>HP-RTU, Electric Backup, Standard Performance</td>
<td>Replaces gas and electric resistance RTUs with standard efficiency HP-RTUs.</td>
</tr>
<tr>
<td>Ideal Thermal Loads</td>
<td>Provides raw thermal loads in time series profile format.</td>
</tr>
<tr>
<td>25% Upsizing for HP-RTU</td>
<td>Size HP-RTU 25% beyond design cooling load as needed to reduce backup heating.</td>
</tr>
<tr>
<td>HP-RTU Lockout Temperature Variation</td>
<td>Increases the lockout temperature of HP-RTU measure to 10°F (default=0°F) to understand impact.</td>
</tr>
<tr>
<td>HP-RTU, Cold Climate HP-RTU Challenge</td>
<td>Replace gas and electric resistance RTUs with HP-RTUs meeting the performance specification of the cold climate HP-RTU challenge.</td>
</tr>
<tr>
<td>Demand Flexibility Measures</td>
<td>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.</td>
</tr>
</tbody>
</table>

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