Impact Analysis of Transitioning to Heat Pump Rooftop Units for the U.S. Commercial Building Stock

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Introduction

Decarbonizing U.S. Commercial Buildings

- 25% of energy consumed in U.S. commercial buildings is from on-site combustion of fossil fuels for space heating [1]
- Decarbonization initiatives require electrification of space heating
- Rooftop units (RTUs) are the most prominent HVAC system type in commercial buildings (~45% stock floor area)
- Heat pump RTUs (HP-RTUs) may offer an impactful decarbonization pathway

Image from: https://www.daikinapplied.com/products/rooftop-systems/rebel

Problem Statement

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

Will transitioning to HP-RTUs…

- Reduce carbon emissions in my city?
- Save energy?
- Overload the grid?

Building Stock Energy Modeling

A typical energy model represents the operation of a **single building**

Image: https://www.northwestern.edu/campus-experience

A stock energy model represents the operation of **all buildings in the "stock"** (a city, state, country, etc.)

Image: https://www.trip.com/blog/iconic-chicago-skyline-buildings-and-how-to-explore/

ComStock

ComStock™ is a highly granular, bottom-up energy model of the U.S. commercial building stock.

-350k representative OpenStudio energy models
-Informed by various sources (CBECS, CoStar, industry, etc.)
-Calibrated to regional timeseries data

Public datasets provide building stock characterization, annual/sub hourly energy, measure savings, and emissions data from county to national scale.

Alignment and Impact

We are putting information in the hands of decision makers

In support of DOE goals to increase building energy efficiency, accelerate building electrification, and do so in ways that prioritize equity, affordability, and resilience

What the Datasets Provide

- Building stock characterization
- When and how buildings use energy
- Potential impacts of energy efficiency
- Information on time-sensitive value of energy resources
- Potential impacts of building electrification

How the Information Is Used

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

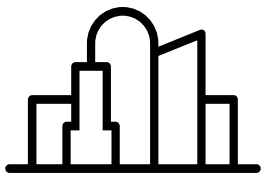
Methodology

ComStock Workflow

The Making of the Dataset:

- Describe the U.S. building stock quantitatively using best-available public data
- Sample the description
- Model the samples
- Model changes to the samples – energy efficiency, electrification, etc.
- Publish description, samples, models, results, aggregations, visualizations, and documentation

ComStock



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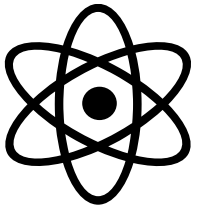

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Building stock characteristics database

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

Physics-based computer modeling

- Representative set of 350k OpenStudio energy models
- Apply “what if” scenarios

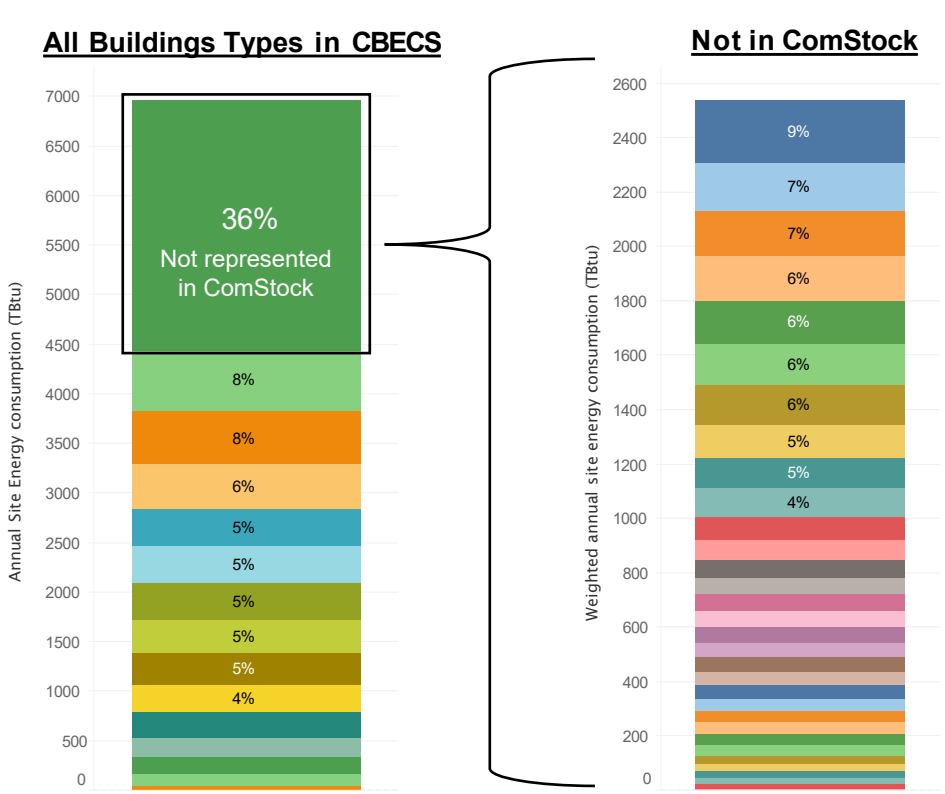
High-performance computing

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

What Does ComStock Model?

ComStock models ~64% of commercial building energy in the United States [2]

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



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 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

The "stock" in this presentation describes the commercial building types modeled by ComStock

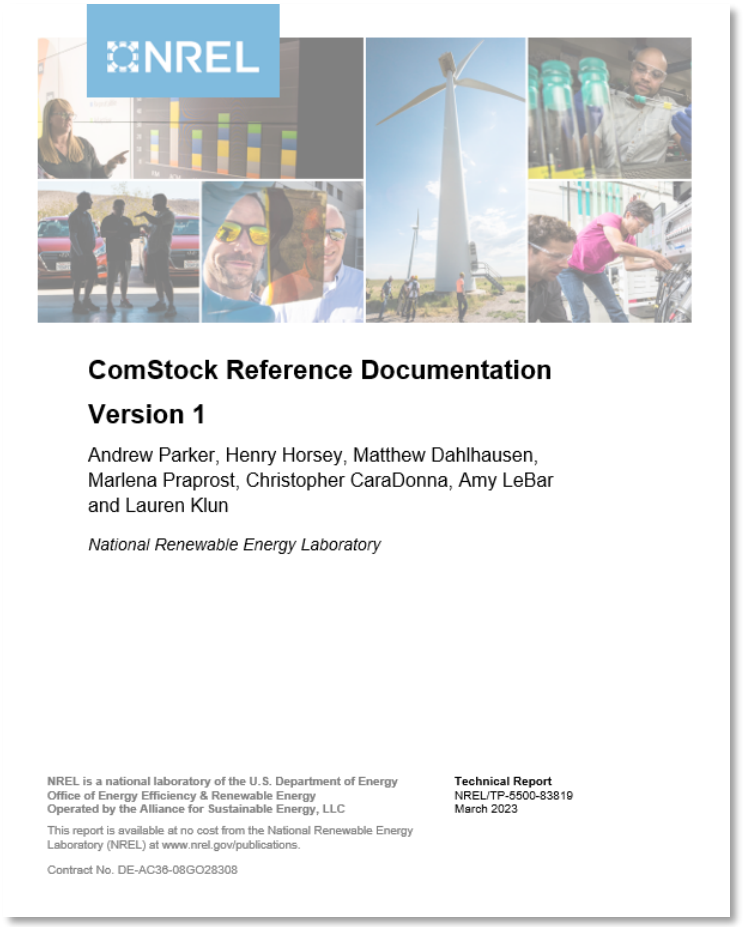
ComStock Documentation Released

ComStock Documentation is now public

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

Link

https://www.nrel.gov/docs/fy23osti/83819.pdf



Available Measures in ComStock

Measure Name	Description	% of Stock Floor Area
HP-RTU Retrofit	Replace gas and electric RTUs with HP-RTU.	45%
Rooftop Ventilator + HP Split System	Replace gas and electric RTUs with Rooftop Ventilator + HP Split System in small commercial buildings (<20,000sf).	11%
Air to Water HP Boiler Retrofit	Replace gas boilers with heat pump boilers.	18%
LED Lighting	Upgrade all lighting to LED.	65%
Exterior Wall Insulation	Add exterior wall insulation panels.	98%
Secondary Windows	Add secondary windows.	>99%
Window Replacement	Replace windows.	>99%
Window Film	Add window film to windows.	>99%
Roof Insulation	Add roof insulation.	>99%

Measure Documentation: https://nrel.github.io/ComStock.github.io/docs/documentation/measures/measures.html
Public Dataset: https://nrel.github.io/ComStock.github.io/docs/data/published_datasets.html
Data Release Webinar: https://www.youtube.com/watch?v=7BHQfk6kvso&t=2518s

HP-RTU Measure Concept

Measure Concept

- Replace gas and electric RTUs with HP-RTU
- Variable speed, high efficiency (>17 IEER)

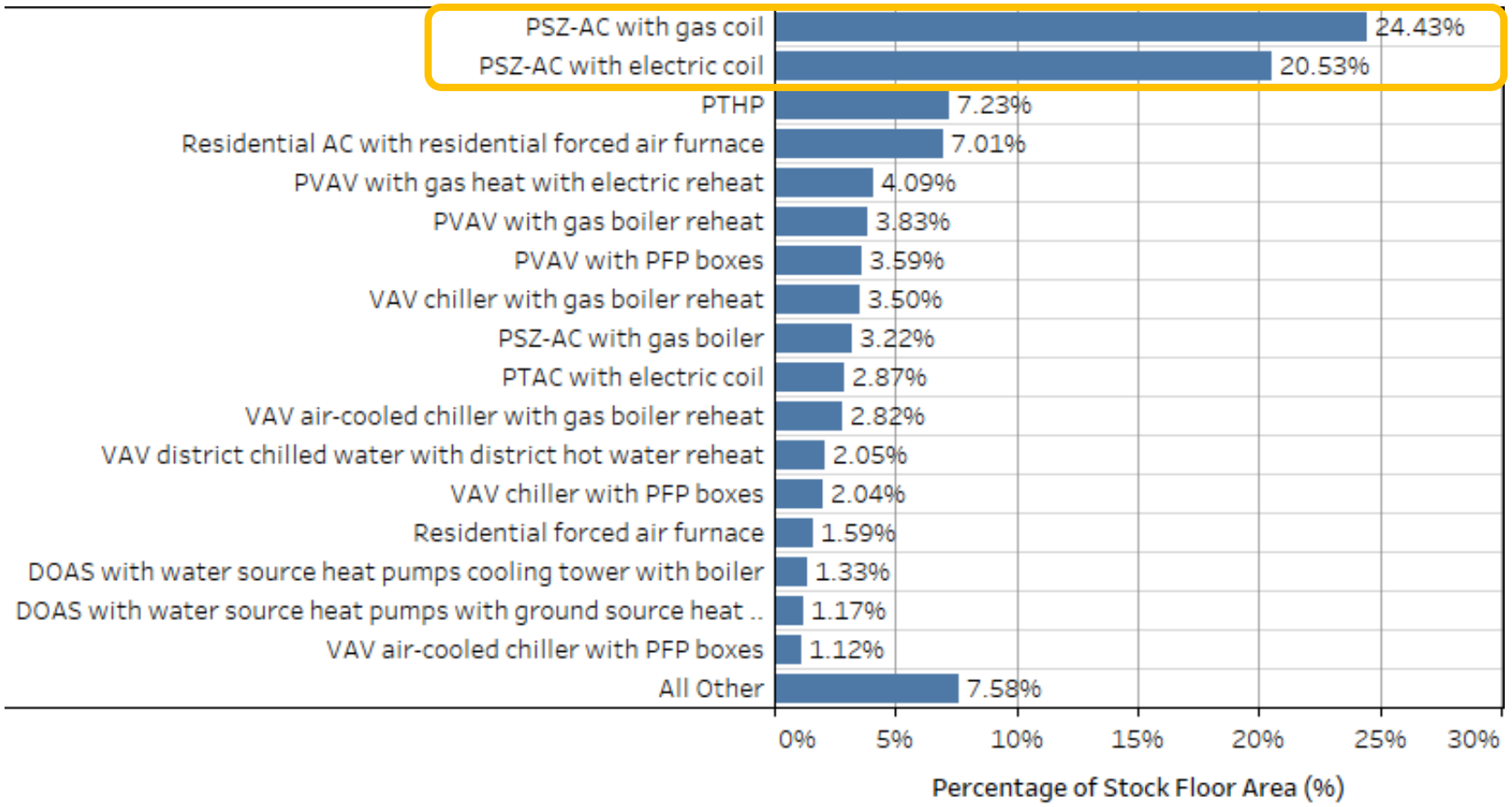
HP-RTU Performance

- **Type:** Variable speed compressor (4 stage) and fan
- **Sizing:** Compressor sized to design cooling load
- **Backup Heat:** Electric resistance; sized as needed
- **Compressor Lockout:** 0°F
- **Defrost:** Reverse cycle
- **Performance Data Source:** Mix of lab testing and manufacturer performance data

Image from: https://www.daikinapplied.com/products/rooftop-systems/rebel

Applicability

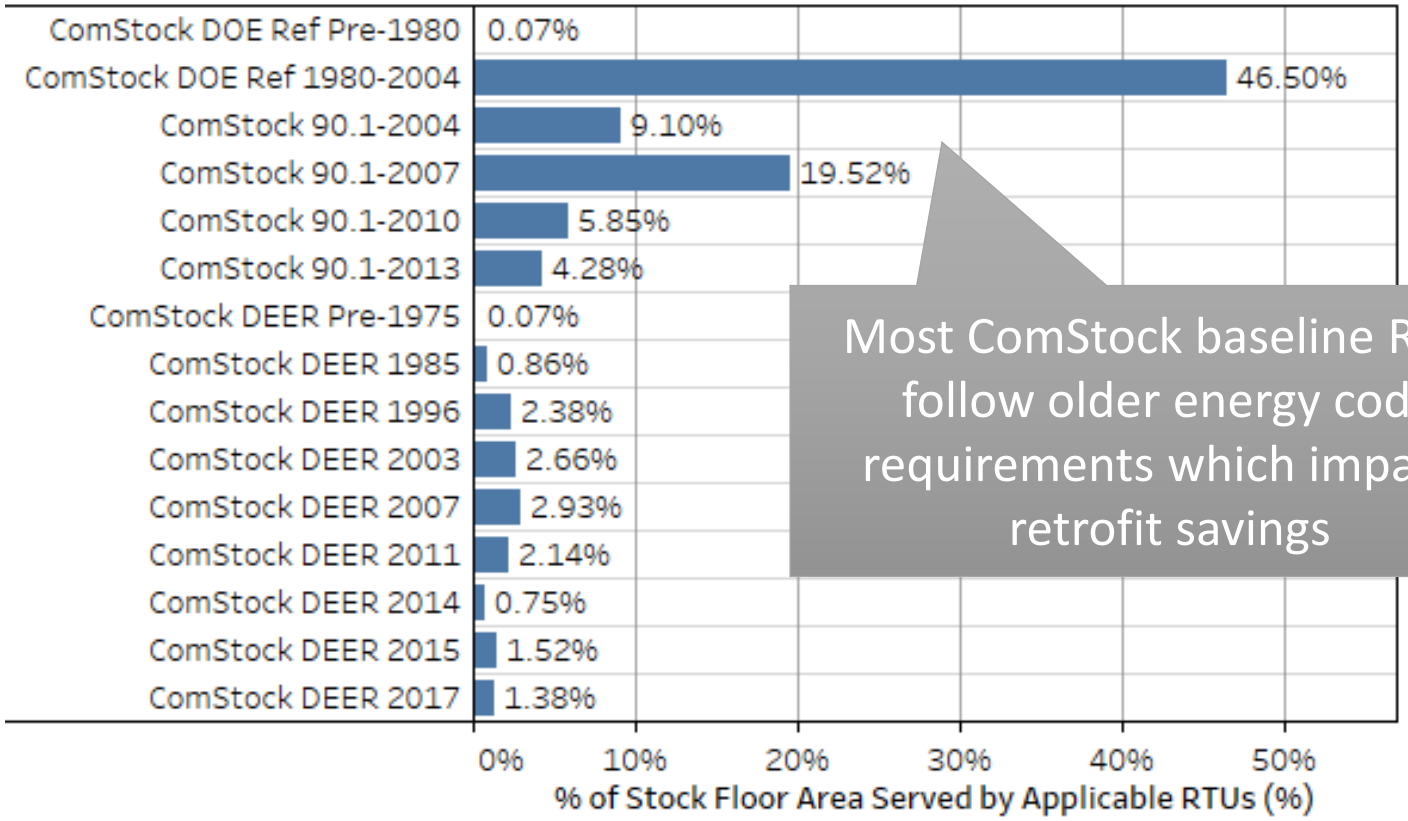
ComStock Baseline HVAC System Type Distribution



- Replacement of existing gas furnace **and electric resistance** RTUs
- Applicable to **~45%** of ComStock floor area

ComStock Baseline RTUs

ComStock Code Year Followed for RTUs



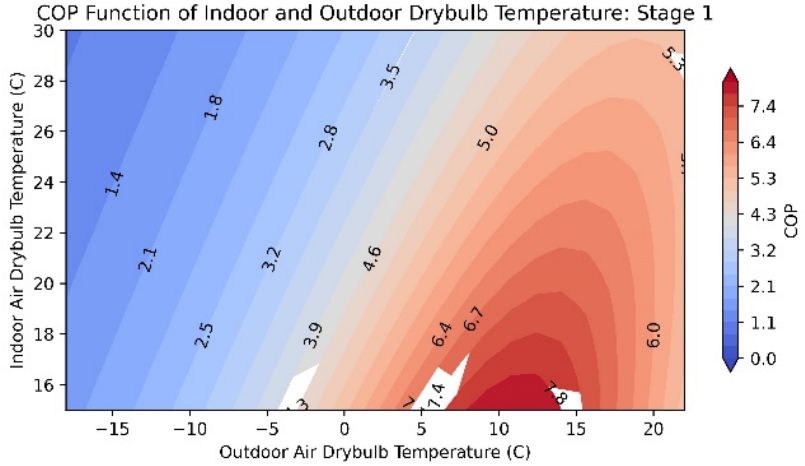
Most ComStock baseline RTUs follow older energy code requirements which impacts retrofit savings

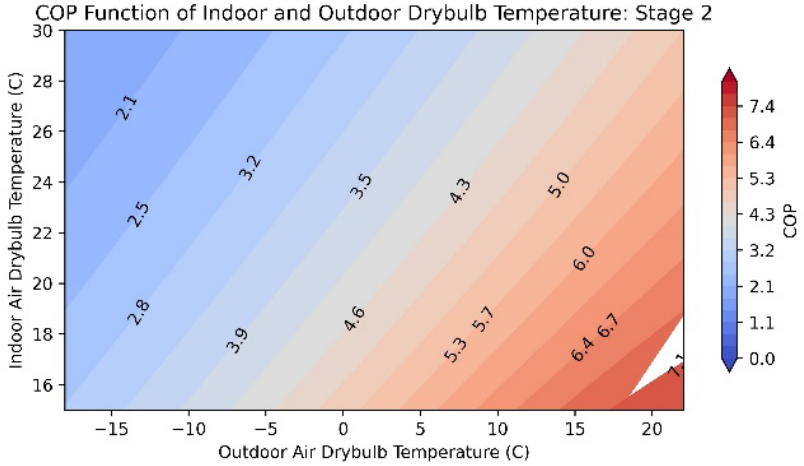
Energy code followed dictates the energy efficiency of the replaced baseline RTUs:

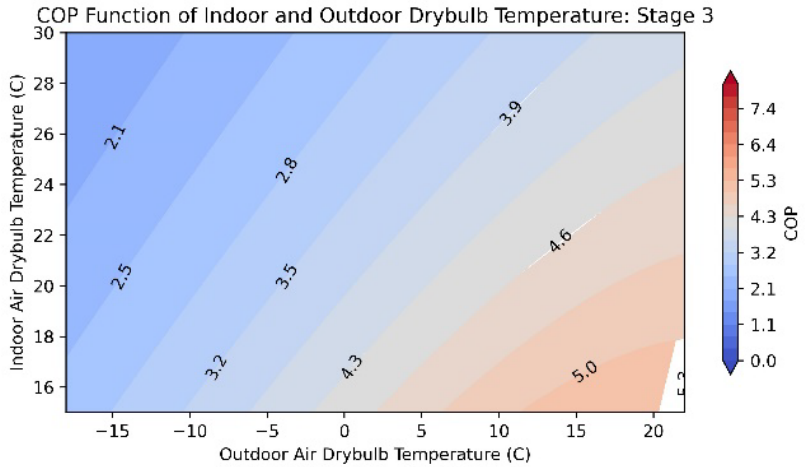
- Cooling efficiency
- Economizers
- Energy Recovery
- Demand Control Ventilation
- Fan Power

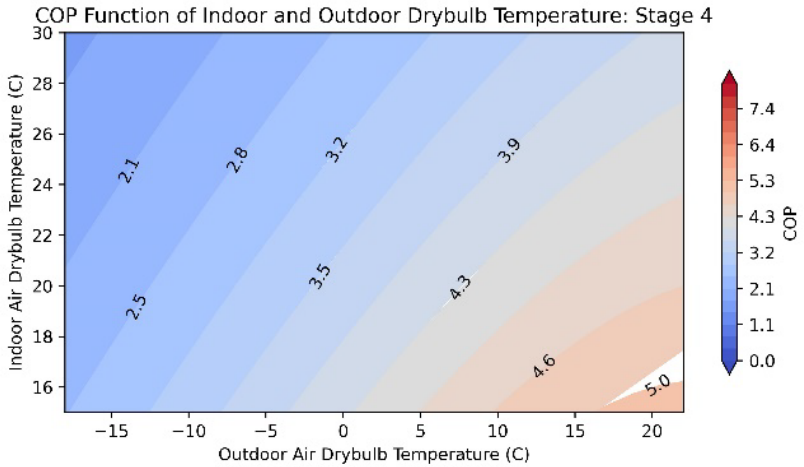
Current ComStock results are for the building stock circa 2018

Heating Performance Maps: COP



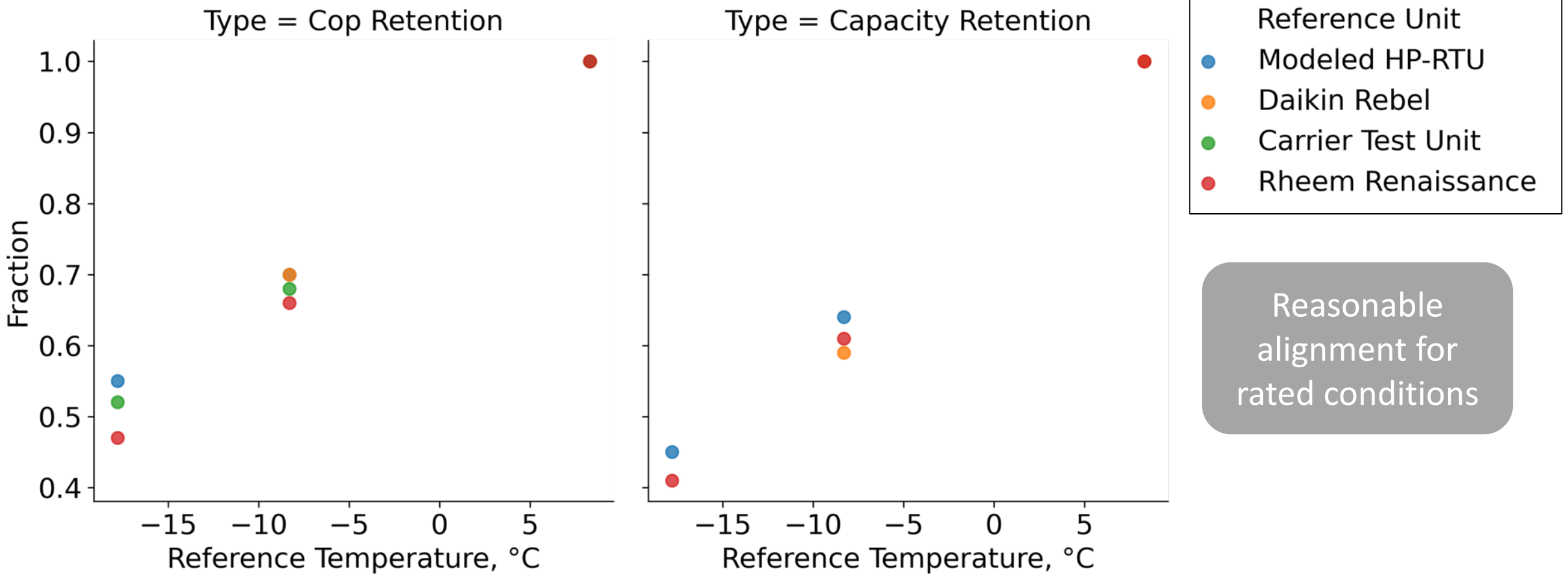






- COP as a function of temperature for 4 heating stages
- Generally higher COPs at warmer outdoor air temperatures and lower compressor speeds
- Other performance maps available for heating capacity and cooling in report

Rated Performance Comparisons



Reasonable alignment for rated conditions

Greenhouse Gas Emissions

Electricity

- 3 grid electricity scenarios compared today; more included in published dataset
- 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 HighRECost	2022	15 years	NREL Cambium [3]
LRMER LowRECost	2022	15 years	NREL Cambium [3]
eGRID	2021	N/A	EPA eGRID [4]

On-Site Combustion Fuels

- Values from Table 7.1.2(1) of draft ANSI/RESNET/ICCC 301 [5]

Greenhouse gas emissions in dataset represent equivalent CO_2 emissions.

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

Note on Heat Pump Modeling

- **Limited comprehensive heat pump performance maps exist** which are required for detailed energy modeling. This creates limitations of the understanding of heat pump performance and operation in this work.

- **Heat pump modeling is sensitive** to performance assumptions due to the strong relationship between efficiency and capacity with outdoor air temperature. This impacts both annual energy consumption and peak demand.

- This work attempts to use the most informative data available and makes documented assumptions about heat pump operation and performance. These will notably impact results. **Please consider these assumptions**.

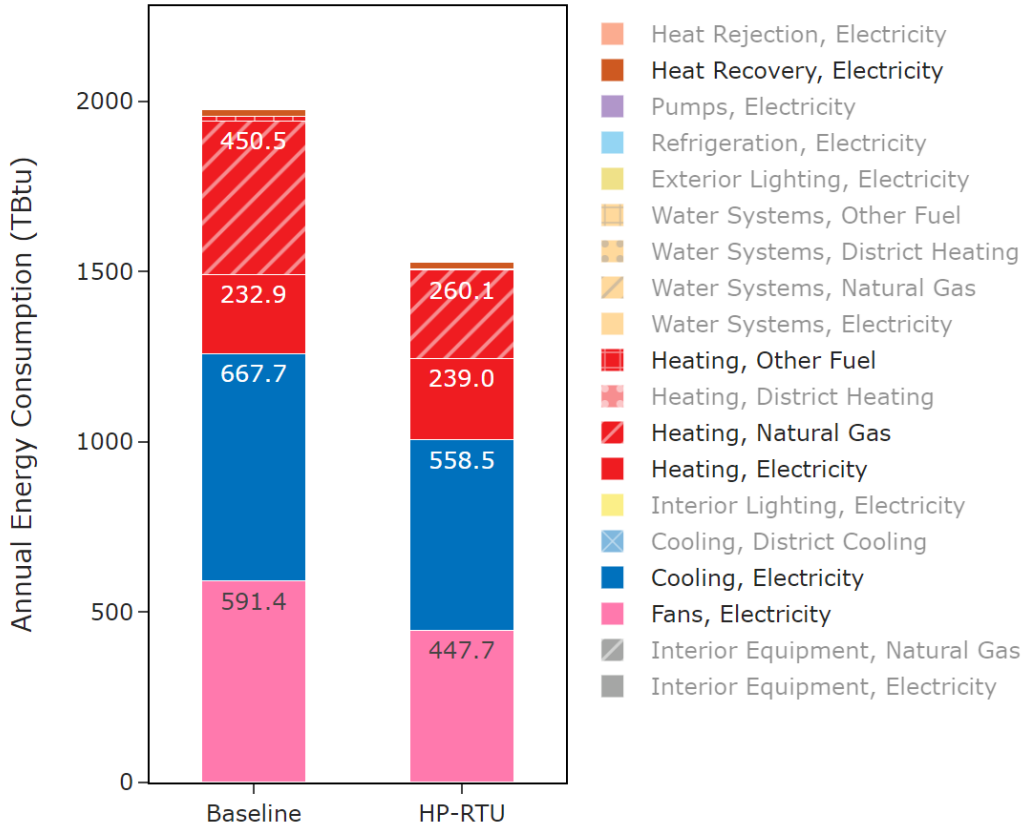
- The assumptions used for the measures **represent one of multiple possible approaches**. They are intended to be reasonable but not necessarily optimal. Assumptions can be modified as our understanding of the technologies improves.

Results

Greenhouse Gas Emissions

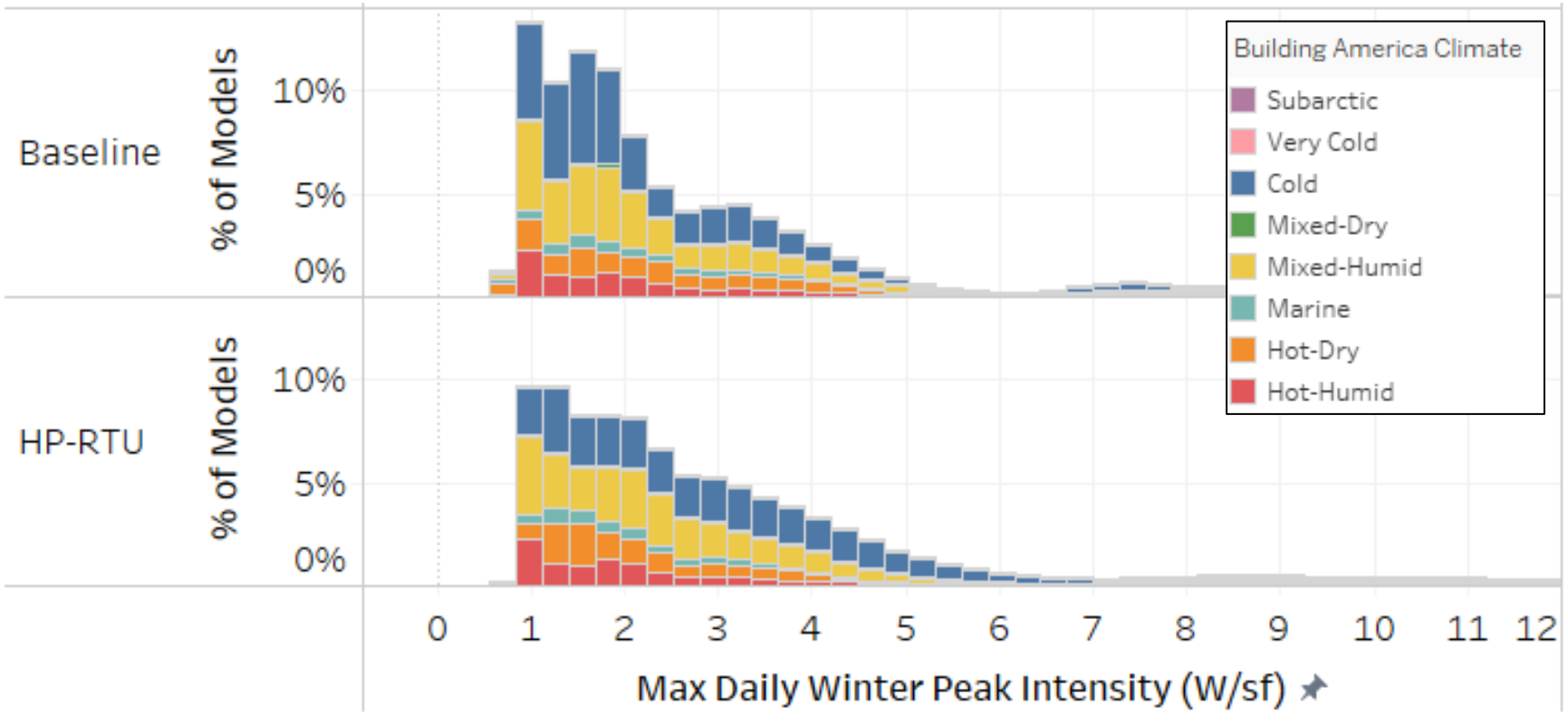
- **42%** stock **heating gas** savings (190 TBtu)
- **-3%** stock **heating electricity** savings (-6 TBtu)
- **16%** stock **cooling electricity** savings (109 TBtu)
- **24%** stock **fan electricity** savings (144 TBtu)
- Cooling and fan savings could also be attributed to high-performance non-HP-RTUs
- Savings associated with premium units

Stock Site Energy by Fuel and End Use



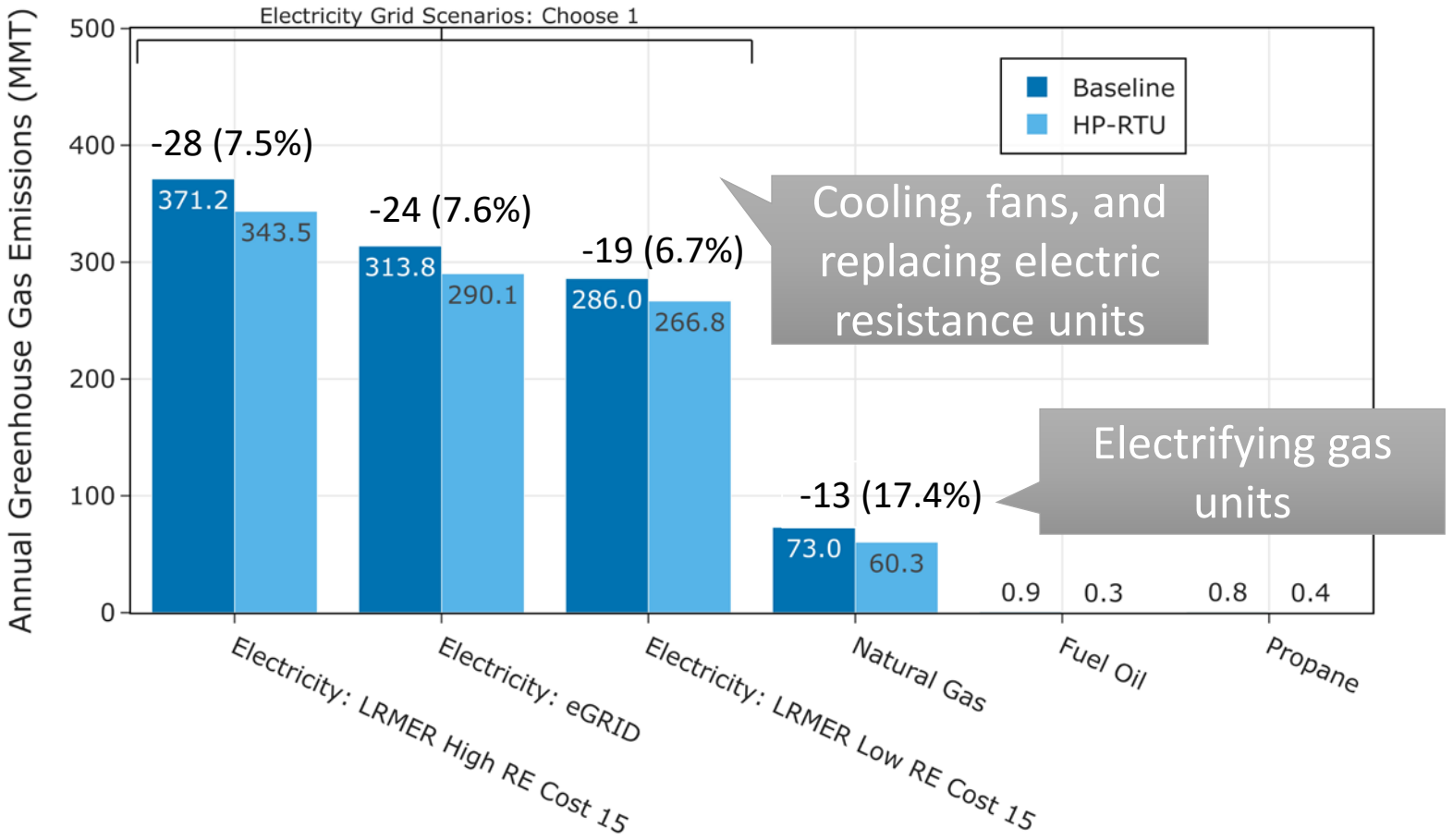
Non-Coincident Peak Demand

Non-Coincident Winter Peak for Buildings With Gas RTUs



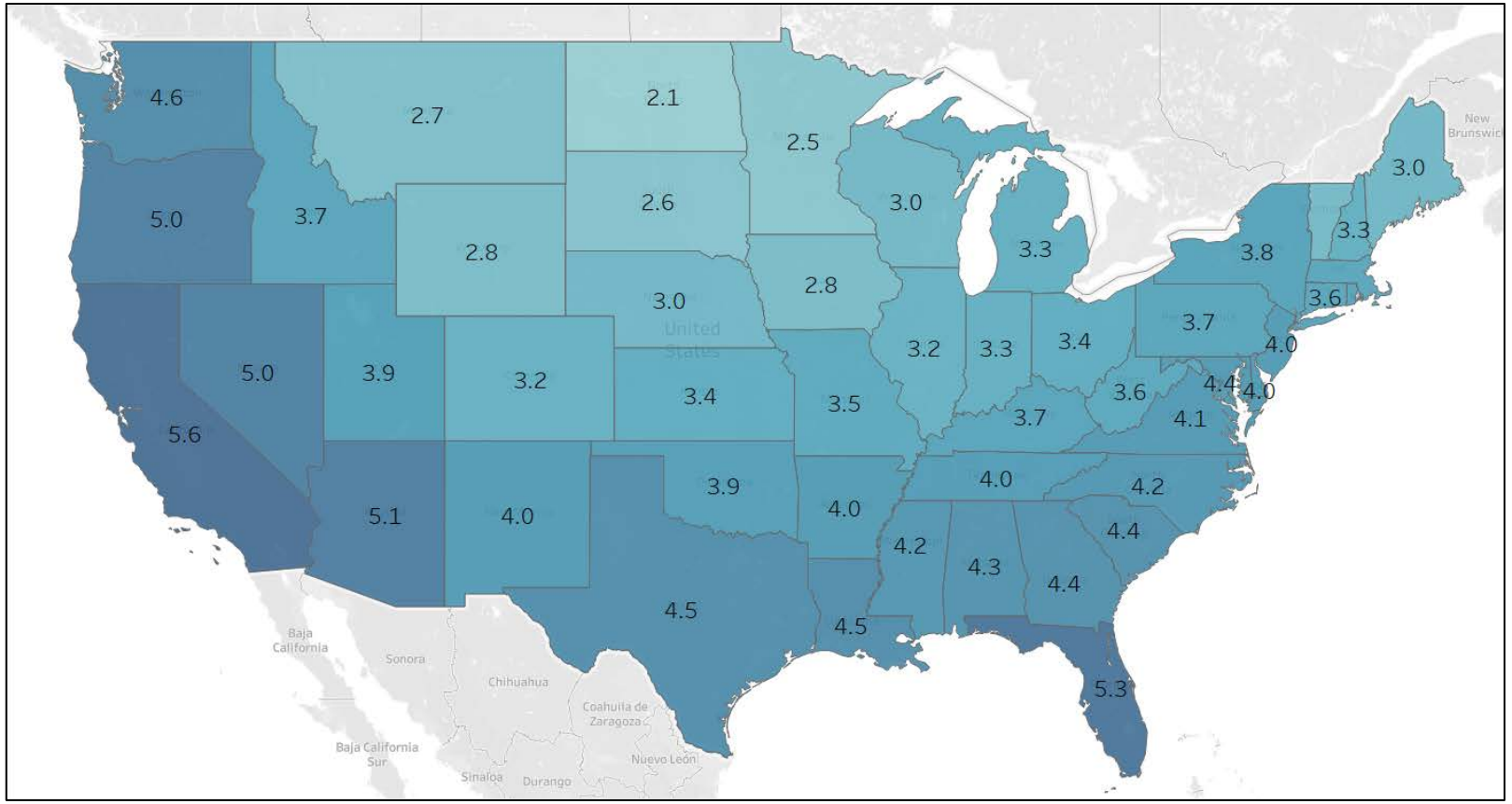
22% winter electric peak intensity increase for median HP-RTU model compared to ComStock baseline gas RTUs

Greenhouse Gas Emissions



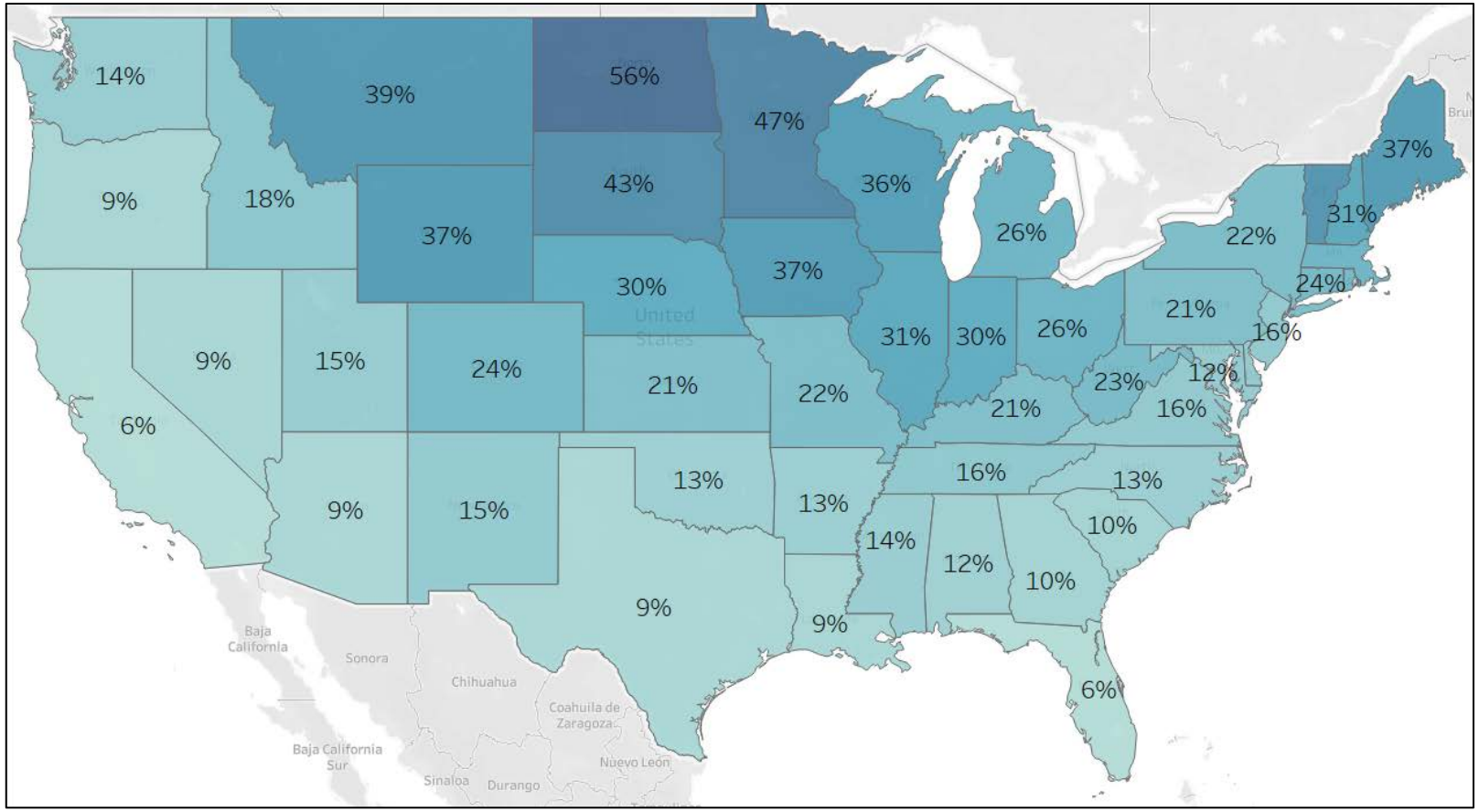
Net emissions avoided across all grid scenarios

Annual Average Heating COP by State



Includes energy consumed for defrost and supplemental heating

Average Percent Supplemental Heat by State



What percentage of HP heating electricity comes from supplemental heat?

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-min intervals	15-min intervals	Customizable	Annual or 15-min 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	OpenEI Data Lake	OpenEI Data Lake	Open EI Data Lake	ComStock.nrel.gov	Scripting Languages

Questions?

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ComStock Documentation Website

- Getting started
- Publications
- Technical documentation

Web Data Viewer

- Graphical in-browser data visualizations
- Custom aggregation tool

AWS OEDI Repository

- Webinar slides
- Metadata & annual results
- Aggregate load profile results
- Individual building models
- Data dictionary and enumeration dictionary
- Geospatial information

Citations

[1] EIA, “2018 Commercial Buildings Energy Consumption Survey (CBECS),” 2018. [Online]. Available: https://www.eia.gov/consumption/commercial/. [Accessed: 14-Nov-2022].

[2] EIA, “2012 Commercial Buildings Energy Consumption Survey (CBECS),” 2012. [Online]. Available: https://www.eia.gov/consumption/commercial/.

[3] Gagnon, Pieter. “Cambium | Energy Analysis | NREL.” National Renewable Energy Laboratory. https://www.nrel.gov/analysis/cambium.html.

[4] United States Environmental Protection Agency. 2023. “Emissions & Generation Resource Integrated Database (eGRID).” September 2, 2022. https://www.epa.gov/egrid.

[5] G. Vijayakumar et al., “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.