Grid-interactive efficient buildings: Assessing the potential for demand flexibility alongside energy efficiency

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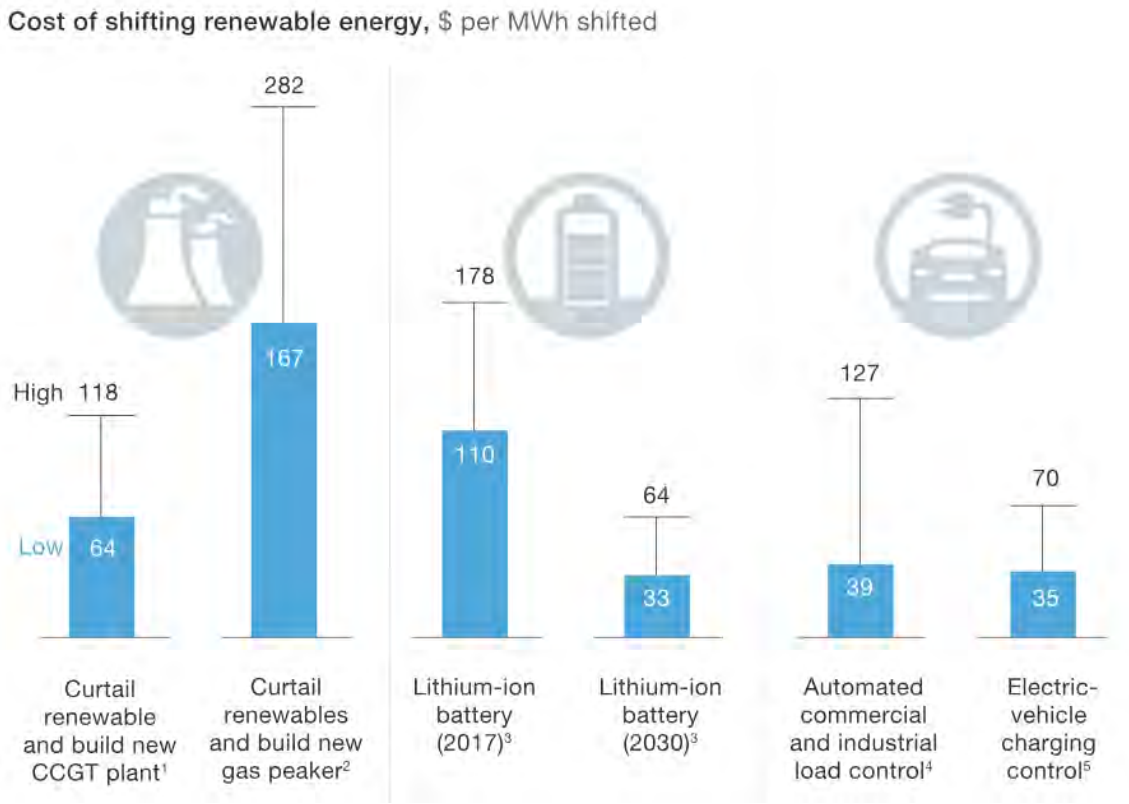
2020 Midwest Energy Solutions Conference; Chicago, IL; February 27, 2020

Problem: What is the U.S. grid "resource" from buildings?

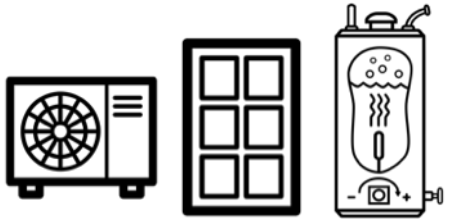
- *Buildings comprise 75% of U.S. electricity demand.*
- *Demand-side flexibility could support variable renewable electricity penetration cost-effectively.*
- *The magnitude of potential demand flexibility from buildings has not been quantified across a portfolio of technologies using a common evaluation method.*



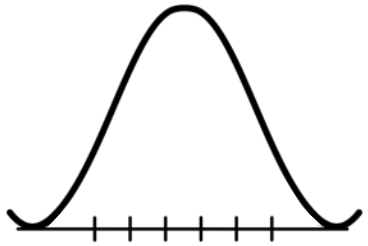
Comparison of the costs per MWh of shifting renewable energy from generation sources, and battery storage/distributed energy resources. Aggregated demand-side flexibility resources are found to be cost-effective and frequently cheaper than the generation alternative. Source: McKinsey.

Solution: Time- and location-sensitive valuation of energy use

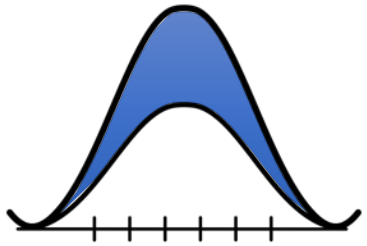
1. Define energy efficiency (EE), demand flexibility (DF), and EE + DF measure portfolios



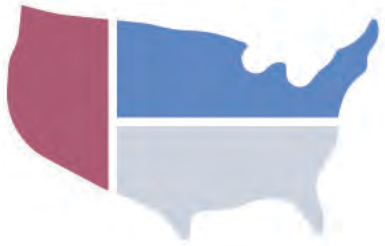
2. Develop hourly fractions of annual baseline load by climate zone, building type, and end use



3. Develop bottom-up EnergyPlus measure simulations and hourly savings fractions based on regional system needs



4. Translate measures to Scout and assess regional/national portfolio potential, annually and sub-annually (2015-2050)



eia

50%

ResStock

eia

scout

U.S. DEPARTMENT OF ENERGY

DRRC Demand Response Research Center

OpenEI

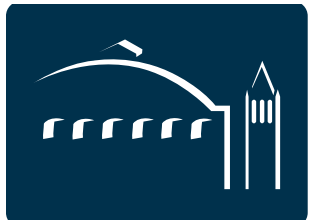
Open Energy Information

OpenStudio

Measures span major residential and commercial electric loads

Measure Type	Measure Name	End Use(s)	Description
Energy Efficiency (EE)	*Scout 'Best Available' ECM portfolio*	*All major end uses*	*Current best available residential efficiency ECMs, definitions posted on Scout GitHub repository*
Demand Flexibility (DF)	*Programmable communicating thermostat (PCT) adjustment*	*HVAC*	*Increase/decrease thermostat set points for one or more peak hours*
	PCT + pre-cooling and heating		*Decrease/increase temperature set points prior to thermostat set point adjustment*
	Grid-responsive WH cycling	*Water Heating*	*Cycle off during peak hours, take load off-peak*
	Grid-responsive dishwasher, washer/dryer cycling; variable speed pool pump	*Appliances*	*Shift dishwasher, clothes washer, and dryer working cycles to off-peak hours; reduce pool pump power during peak hours*
	Low priority device switching	*Electronics*	*Switch off/unplug low-priority devices during peak hours (e.g., TVs, set top boxes, laptops/PCs)*
EE + DF	*PCT + pre-cool/heat + efficient envelope and HVAC equipment*	*HVAC, Lighting*	*Combine EF HVAC strategies with most efficient envelope and equipment to maximize EE, and EF*
	Grid-responsive cycling/control + efficient equipment	*Appliances, WH, Electronics*	*Combine EF WH, appliance, and electronics strategies with most efficient equipment*
	All remaining Scout EE ECMs	*Refrigeration*	*Account for efficiency outside of combined EE+DF measures above*

Measures span major residential and commercial electric loads

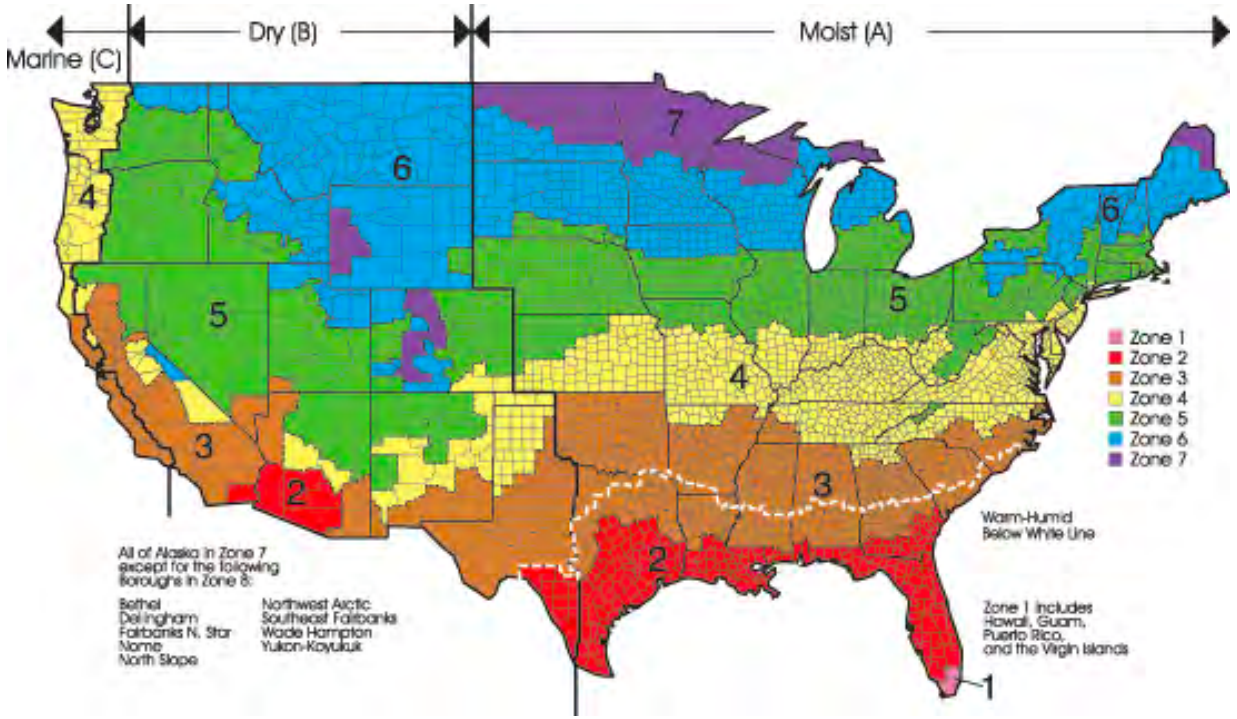


OpenStudio

Measure Type	Measure Name	End Use(s)	Description
Energy Efficiency (EE)	*Scout 'Best Available' ECM portfolio*	*All major end uses*	*Current best available commercial ECMs, definitions posted on Scout GitHub repository*
Demand Flexibility (DF)	*Global temperature adjustment (GTA)*	*HVAC*	*Increase zone temperature set points across facility for one or more peak hours*
	GTA + pre-cooling and heating		*Decrease zone set points prior to GTA*
	GTA + pre-cool/heat + storage		*Charge/discharge ice storage prior/during GTA*
	Continuous dimming	*Lighting*	*Dim lighting by certain percentage for one or more peak hours*
	Low priority device switching	*Electronics*	*Switch off low-priority devices (e.g., unused PCs, equipment) for one or more peak hours*
EE + DF	*GTA + pre-cool/heat + dimming + efficient envelope and HVAC equip., daylight controls*	*HVAC, Lighting*	*Combine EF HVAC/lighting strategies with more efficient envelope/equipment, daylighting, and controls to maximize EE and EF*
	Device switching + efficient electronics	*Electronics*	*Combine EF electronics strategy with the most efficient electronic equipment*
	All remaining EE ECMs	*Refrigeration, WH*	*Account for efficiency outside of combined EE+DF measures above*

Building-level measure operation addresses system-level needs

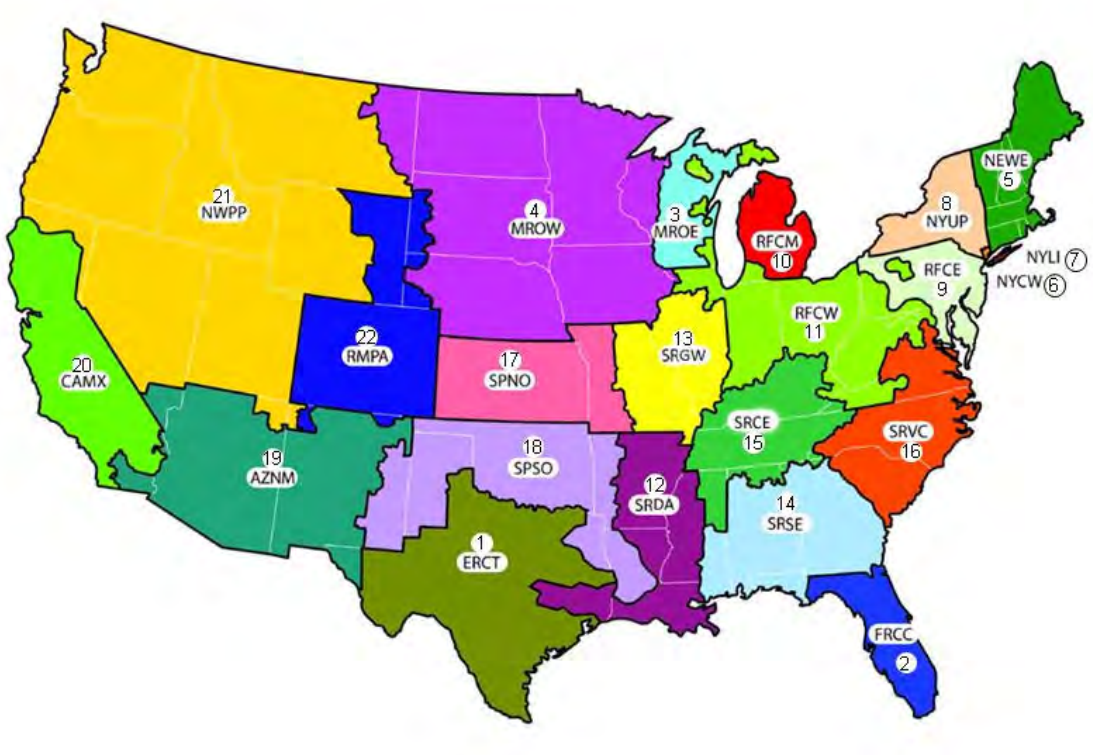
- *Building-level measure operation is modeled in a representative city for 14 ASHRAE/IECC climate zones (excludes 1 and 8)*
- *Representative building types capture variations in loads and operational patterns*
  - *Residential: single family*
  - *Commercial: large office, large hotel, medium office, retail, warehouse*
- *Measures adhere to acceptable service thresholds*



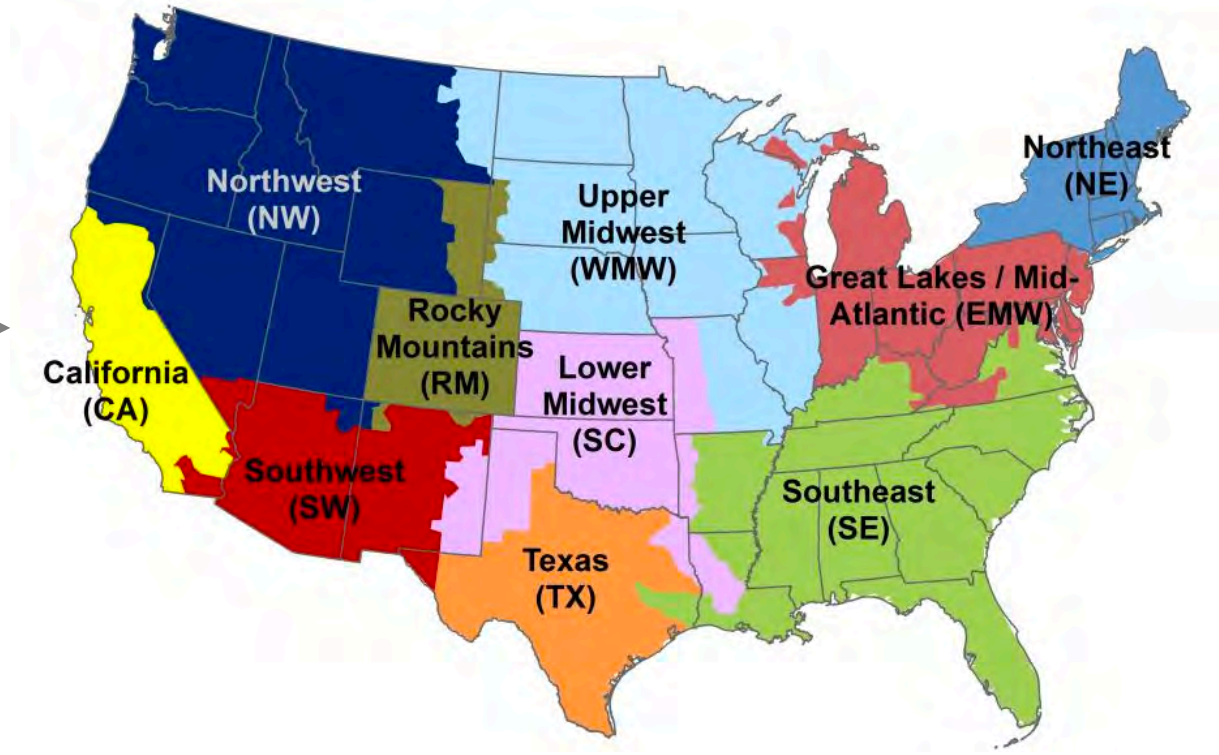
ASHRAE/IECC climate zones

Building-level measure operation addresses system-level needs

- *Measure building-level operation is assessed relative to system-level load shapes for the 22 EIA Electricity Market Module (EMM) regions*
- *EMM region results map to the 10 EPA AVERT regions for easier interpretation*

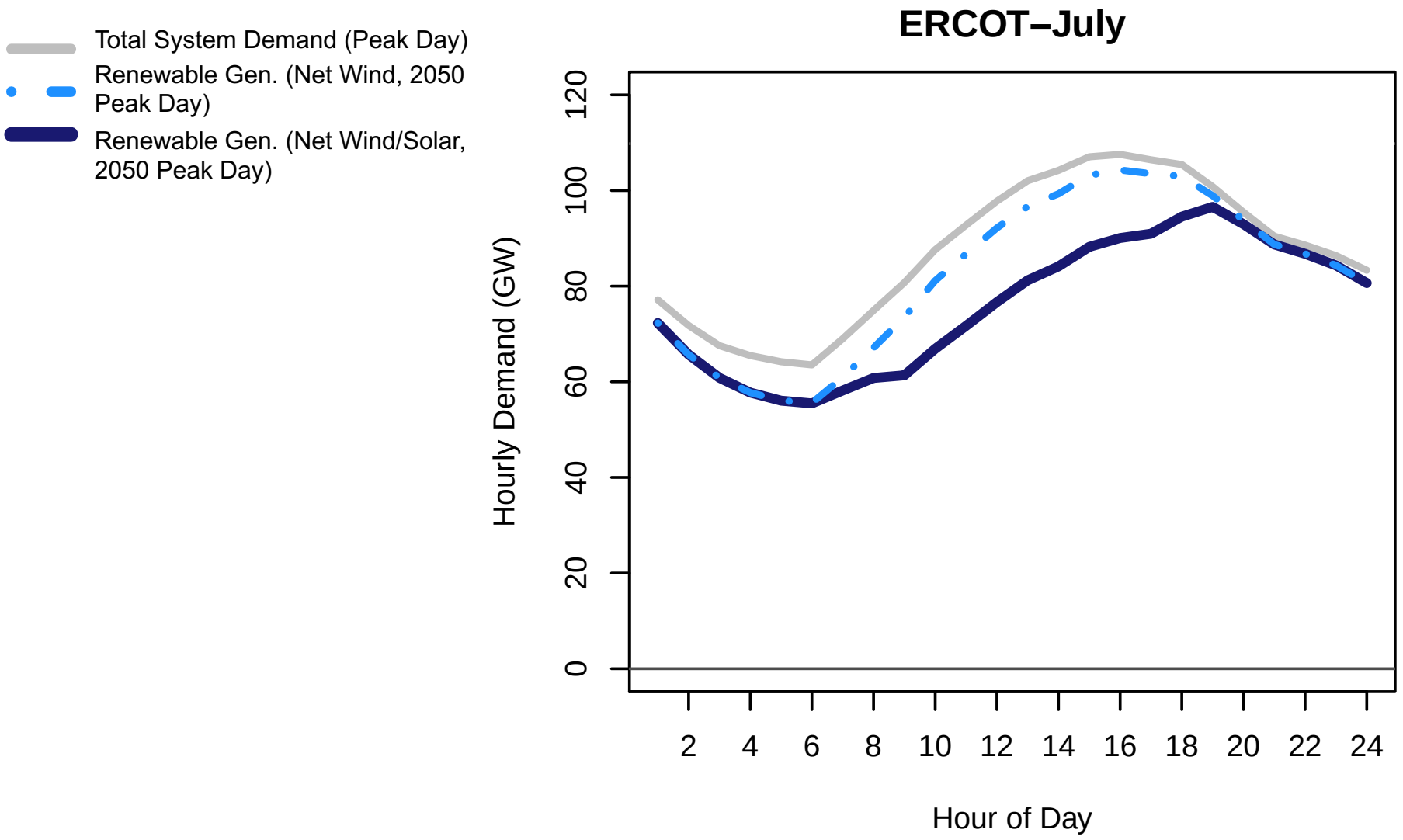


U.S. EIA EMM regions



U.S. EPA AVERT regions

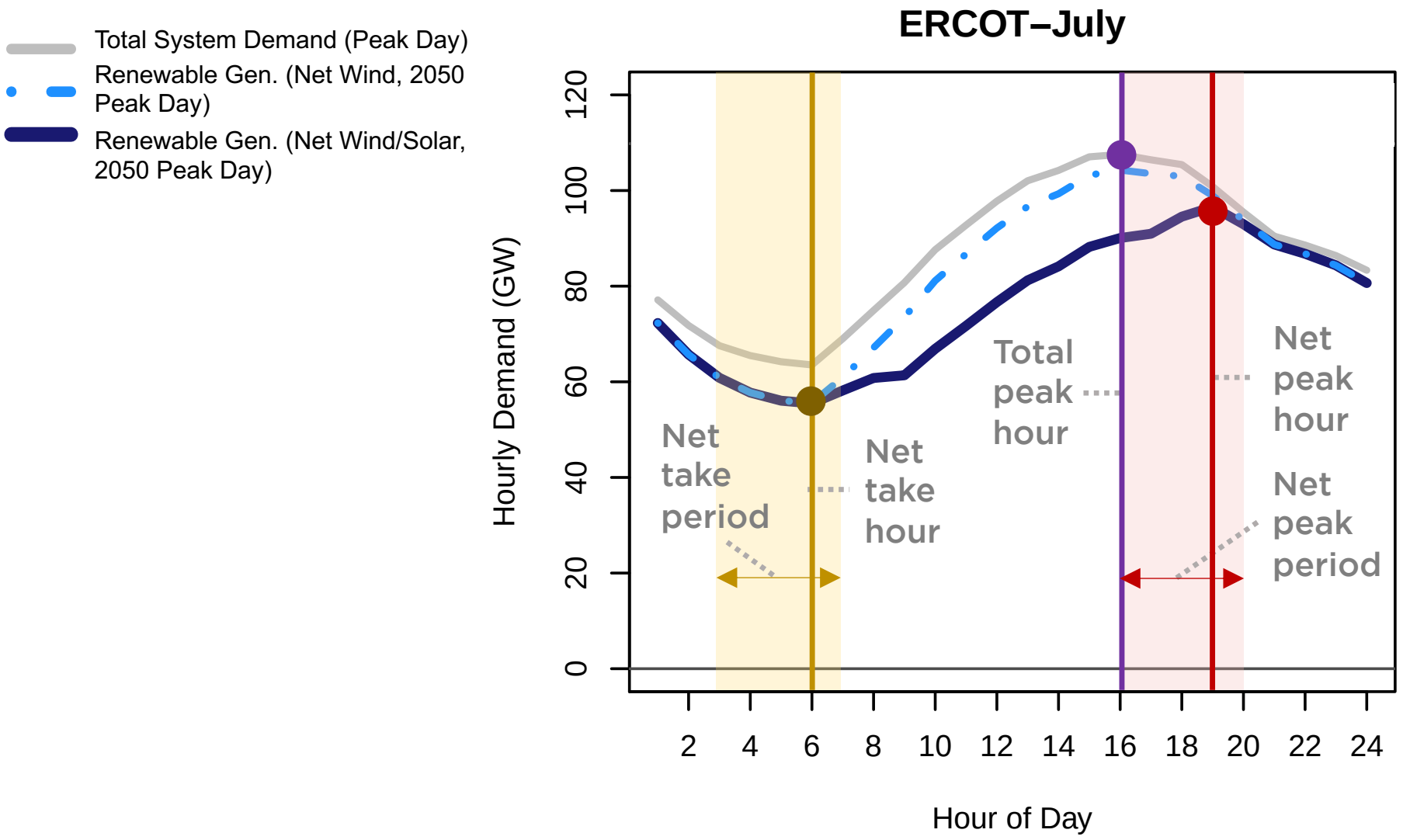
Measures either reduce or build net system loads by time of day



- *Regional net system load shapes for the year 2050 are used as a reference for measure development (year with the highest renewable penetration levels).*

Data: EIA EMM, projection year 2050

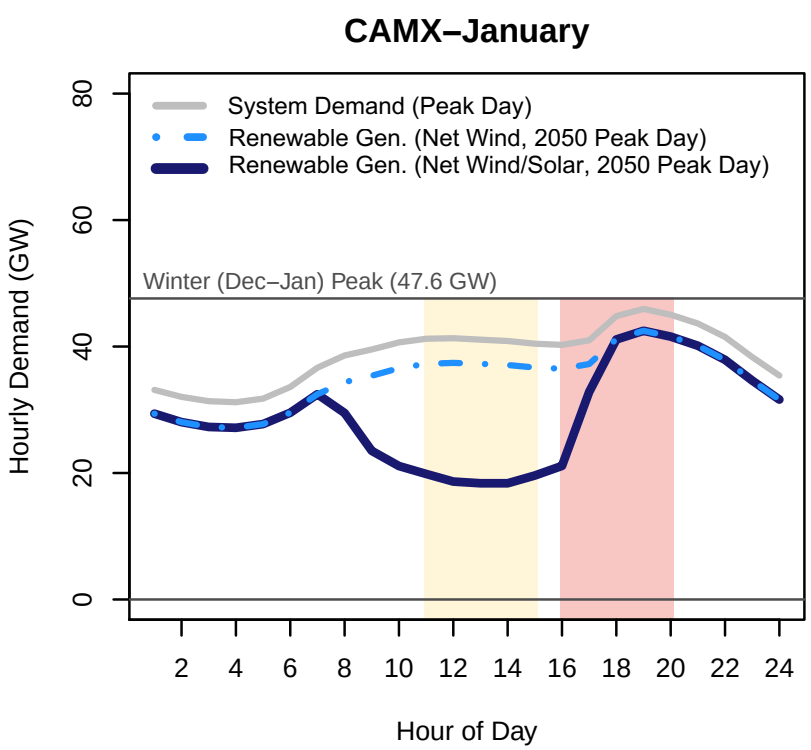
Measures either reduce or build net system loads by time of day

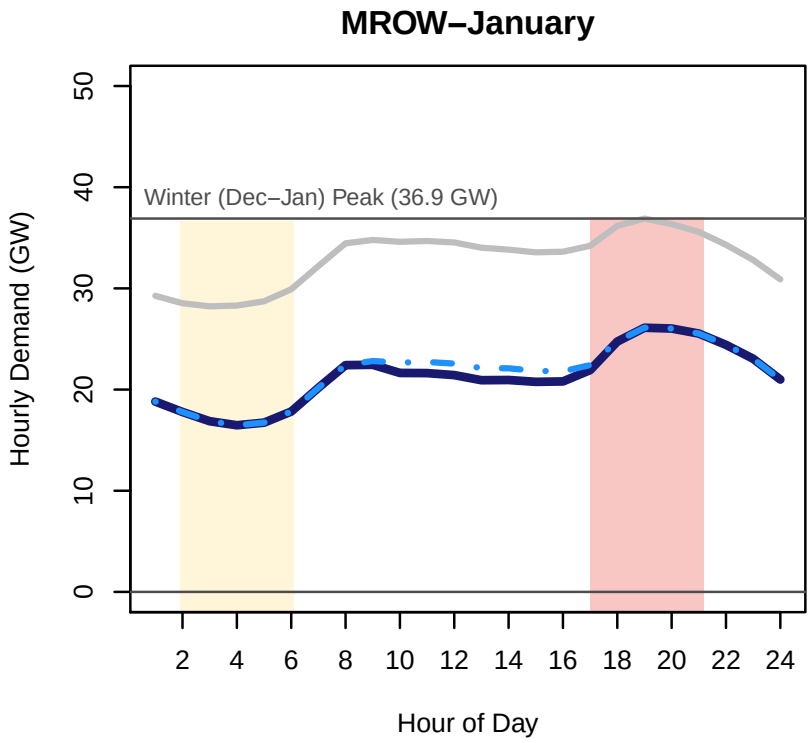


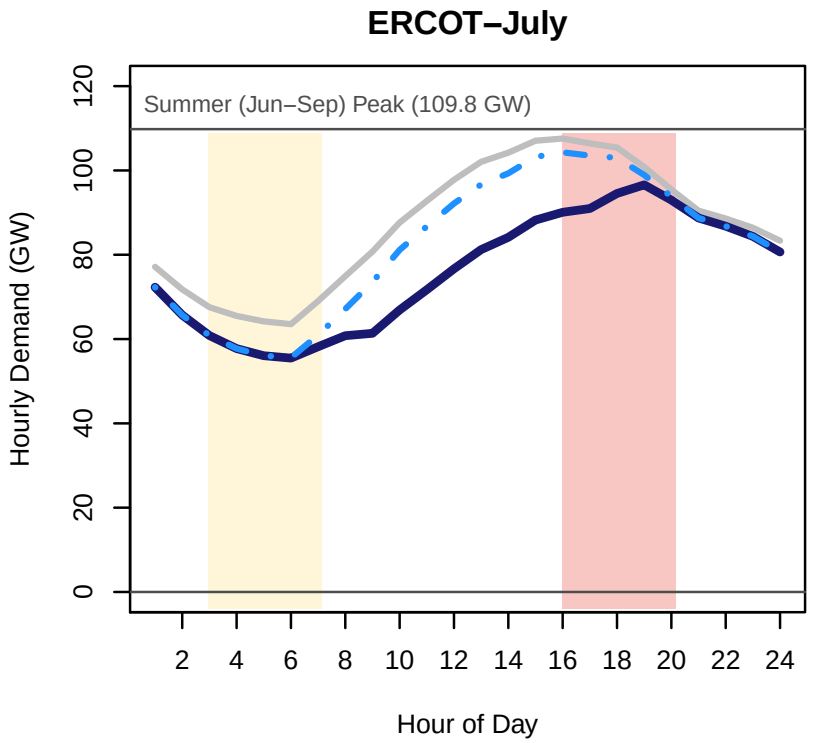
- *Regional net system load shapes for the year 2050 are used as a reference for measure development (year with the highest renewable penetration levels).*
- *Flexibility measures are designed to remove load during net peak periods and build load during net take periods, flattening the net load shape.*

Data: EIA EMM, projection year 2050

Net load shape typologies vary by utility region and season





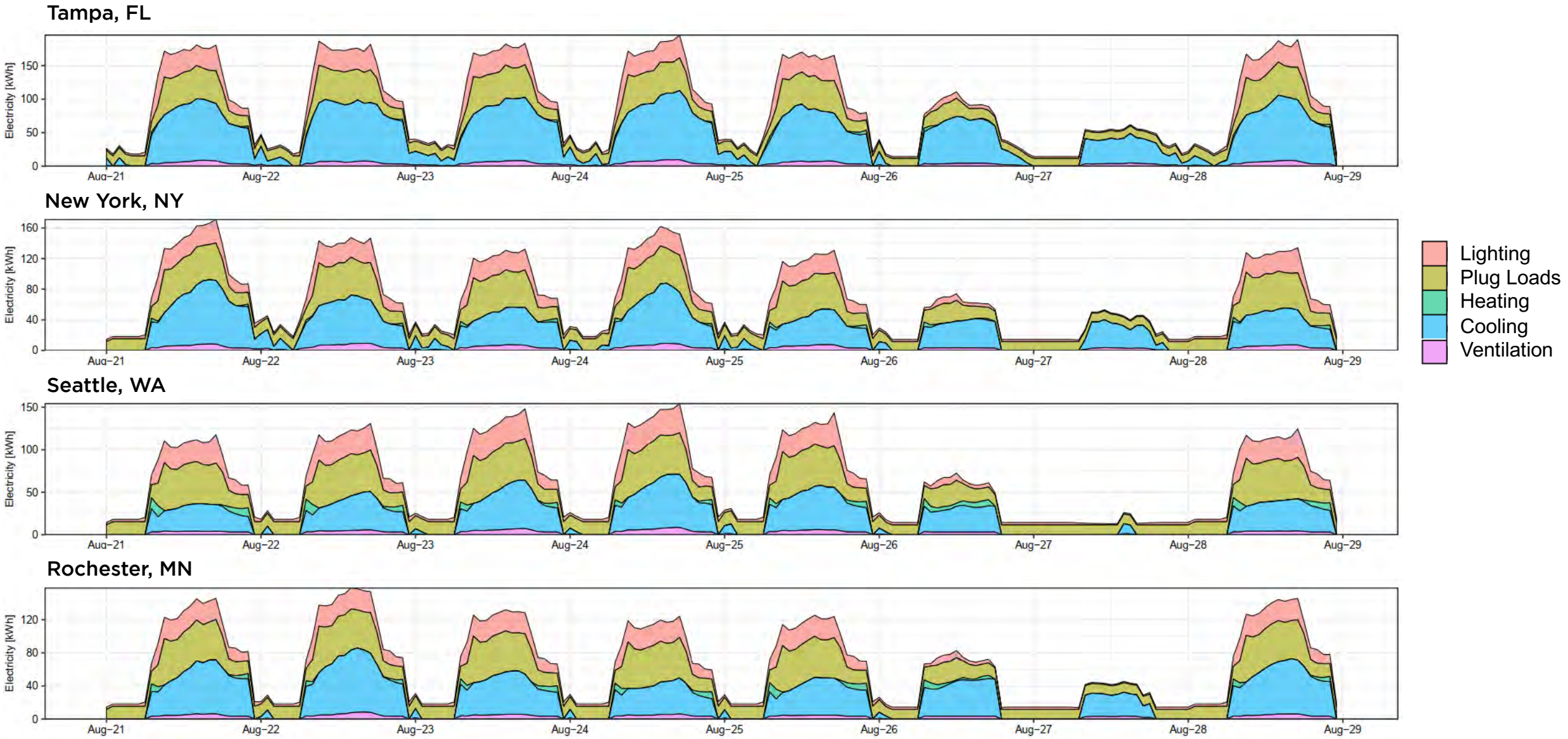


Take period (build load)

Peak period (reduce load)

Data: EIA EMM, projection year 2050

Example commercial baseline loads (August, medium office)



Data: EnergyPlus/OpenStudio Commercial Prototype simulations

Example commercial measure load impacts (medium office)

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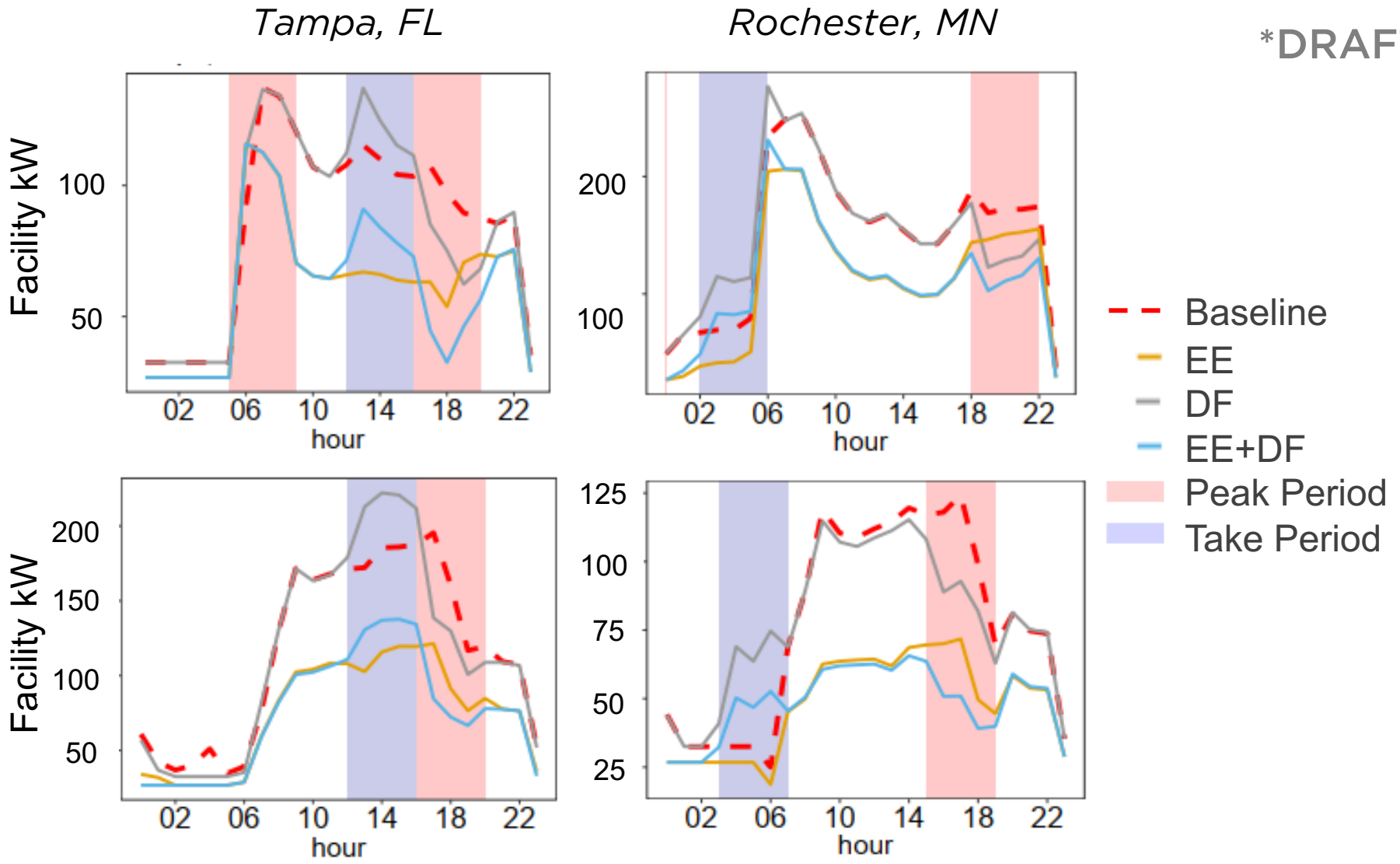
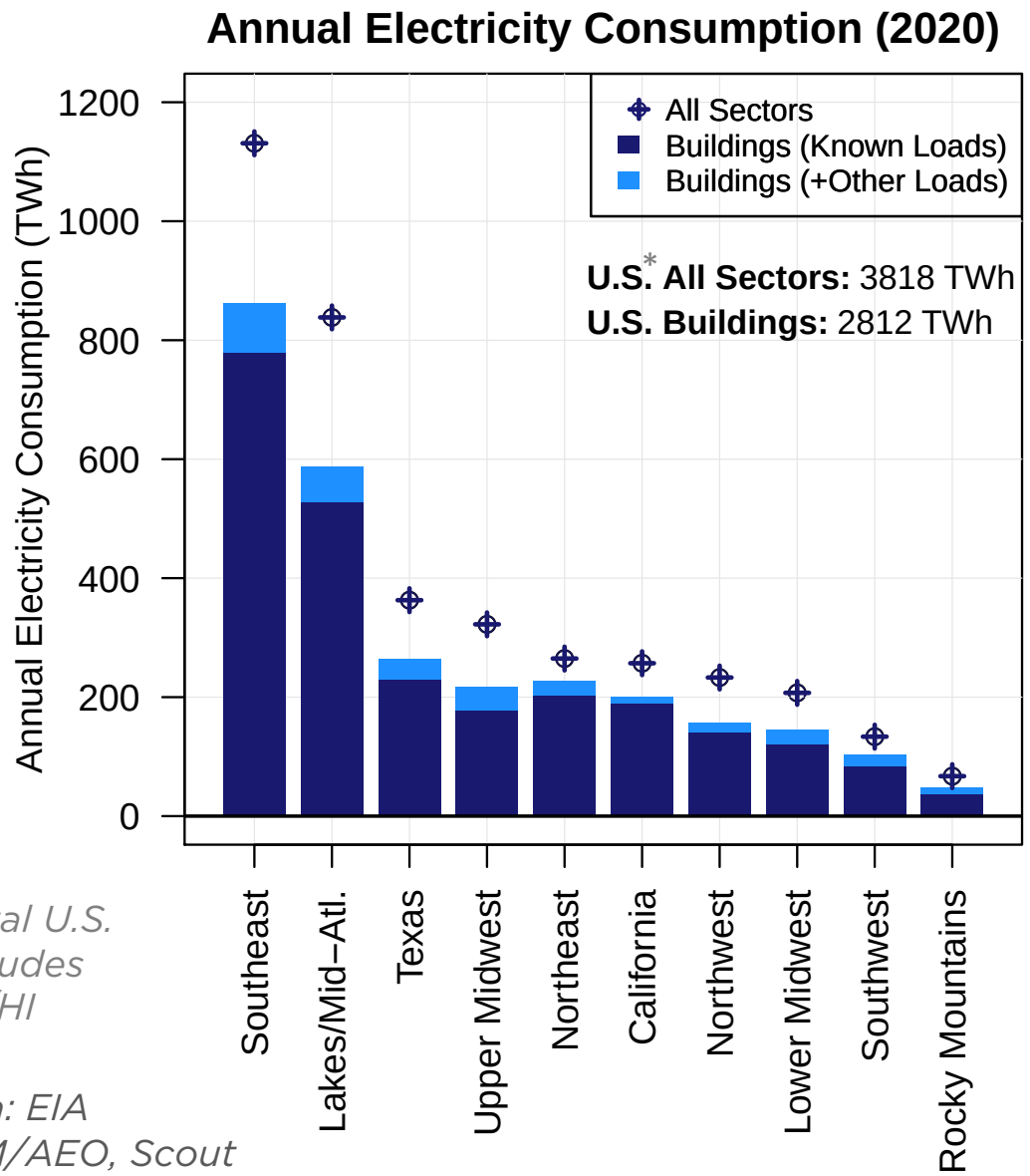
*Example **winter** day*
Tuesday, January 24

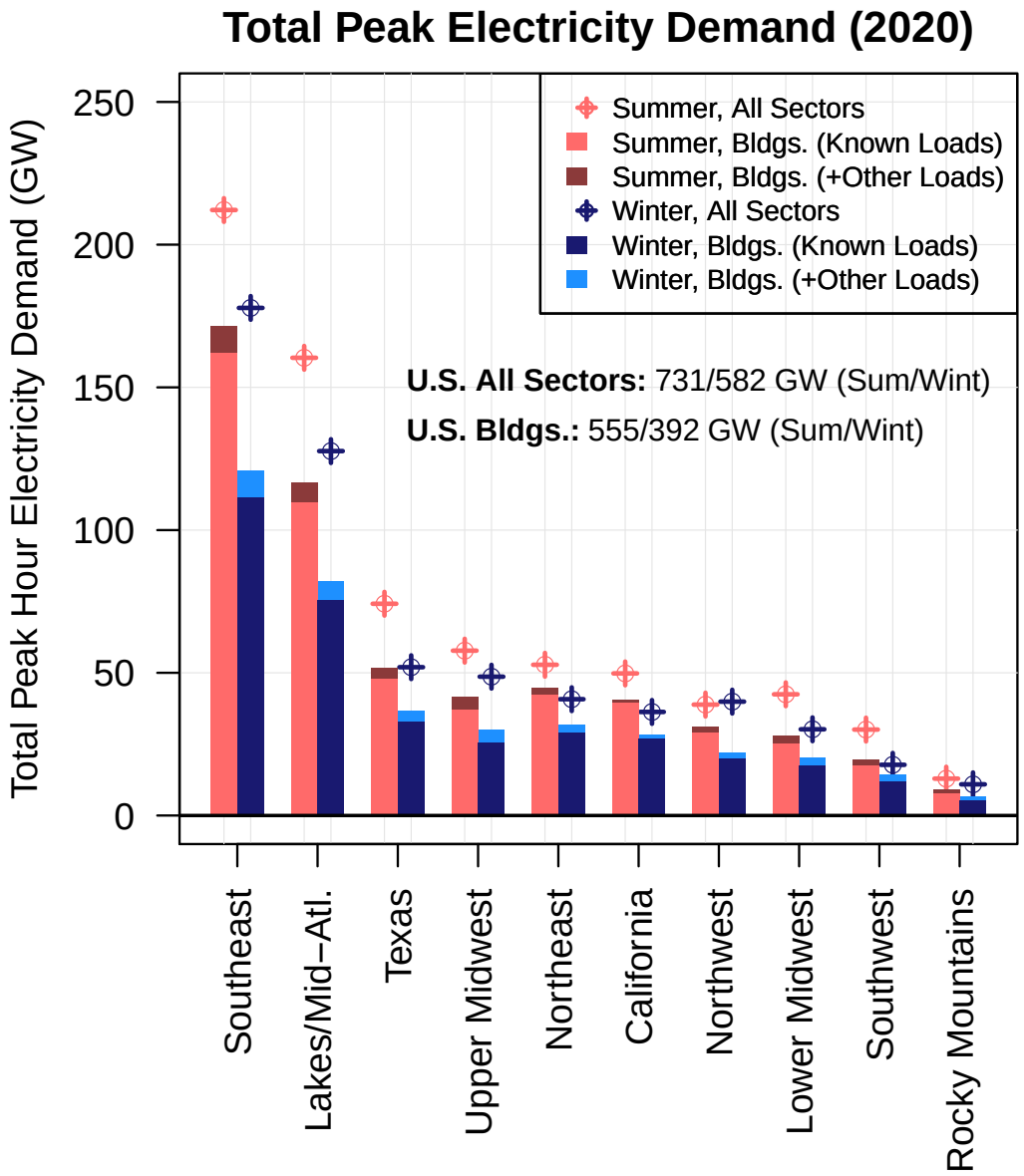
*Example **summer** day*
Thursday, August 24



Data: EnergyPlus/OpenStudio Commercial Prototypes with new measure application

The buildings sector drives U.S. annual and peak electric loads





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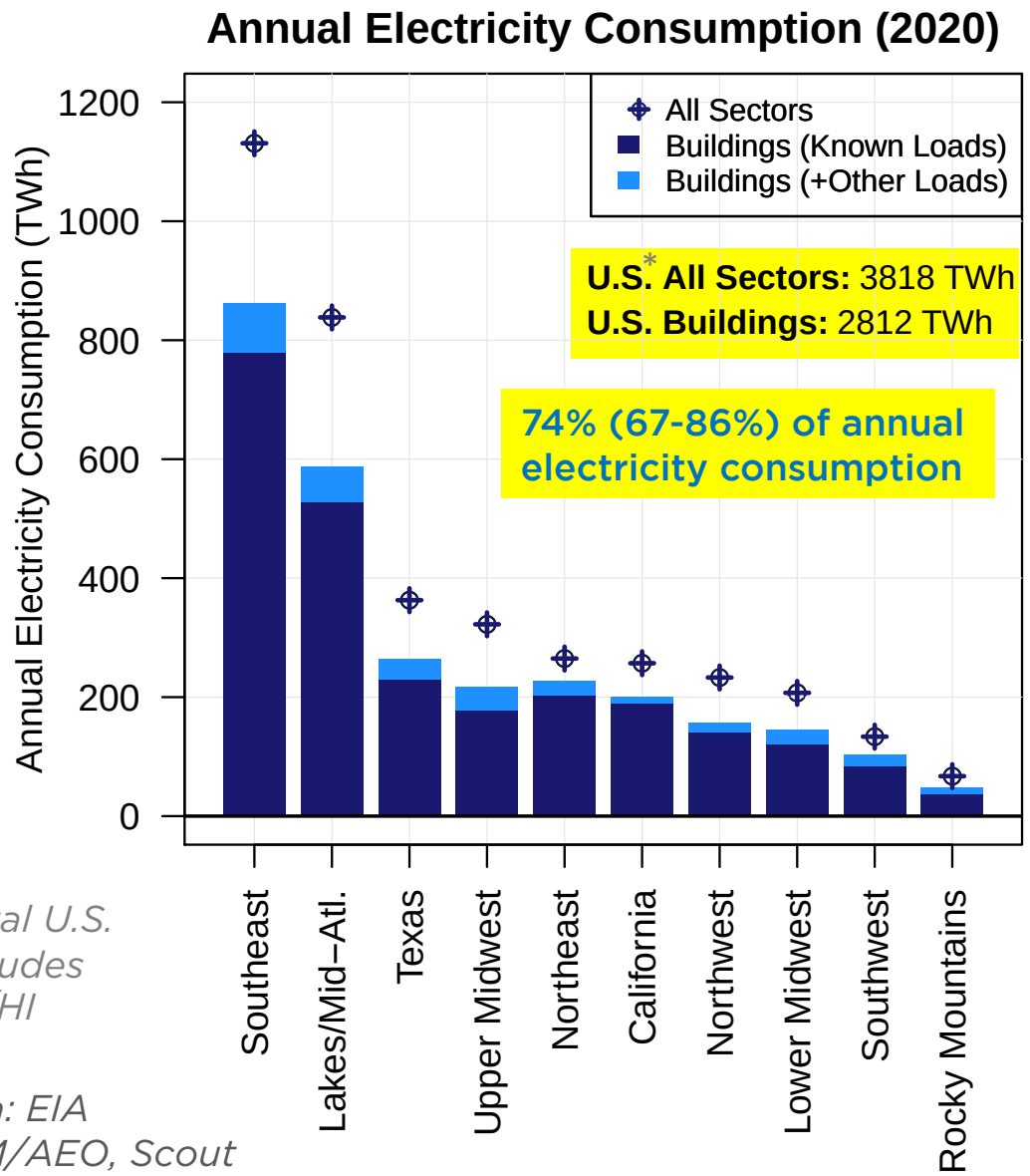
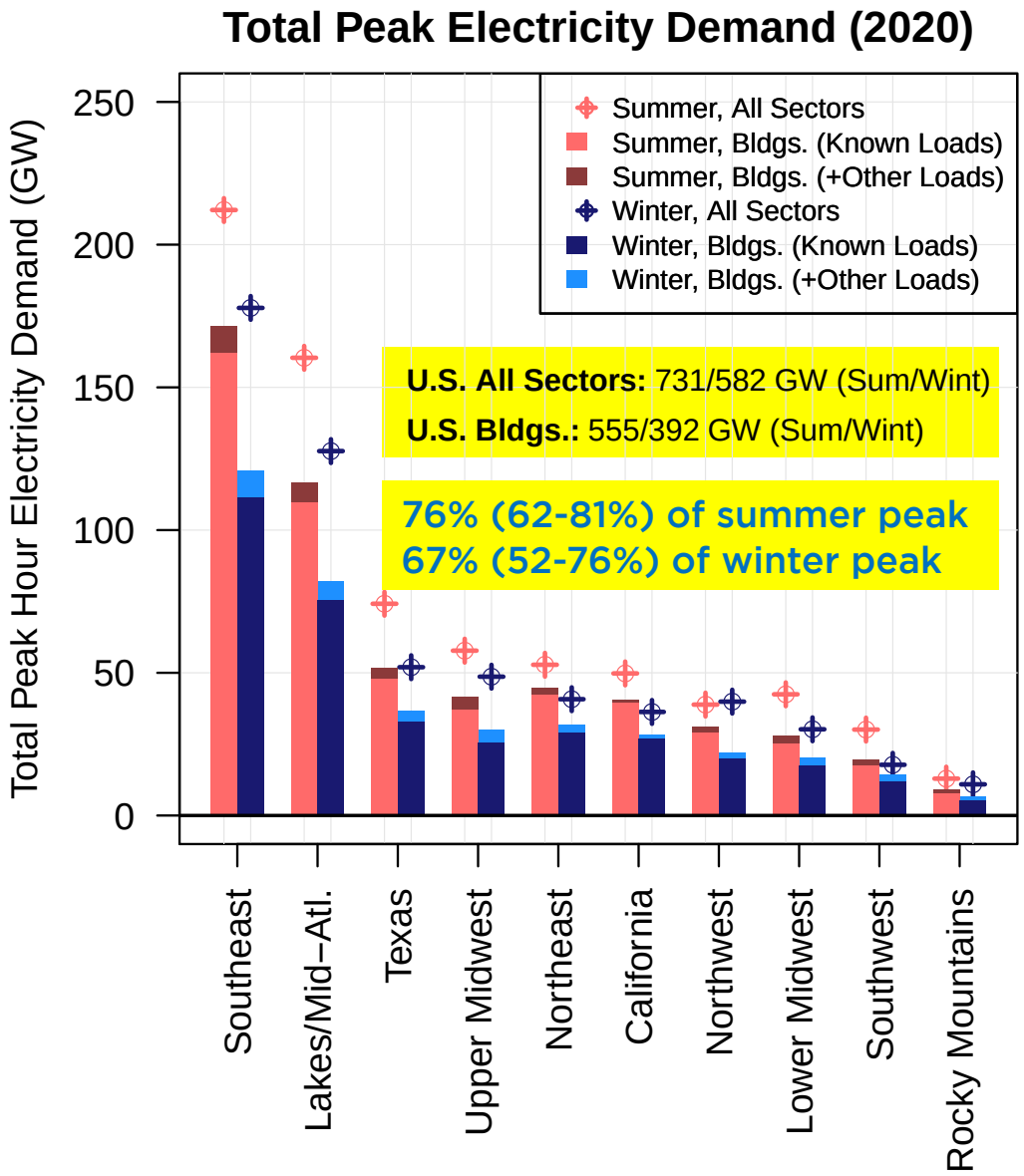
*Total U.S. excludes AK/HI

Data: EIA EMM/AEO, Scout

The buildings sector drives U.S. annual and peak electric loads





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*Total U.S. excludes AK/HI

Data: EIA EMM/AEO, Scout

Efficiency and flexibility are complementary and conflicting

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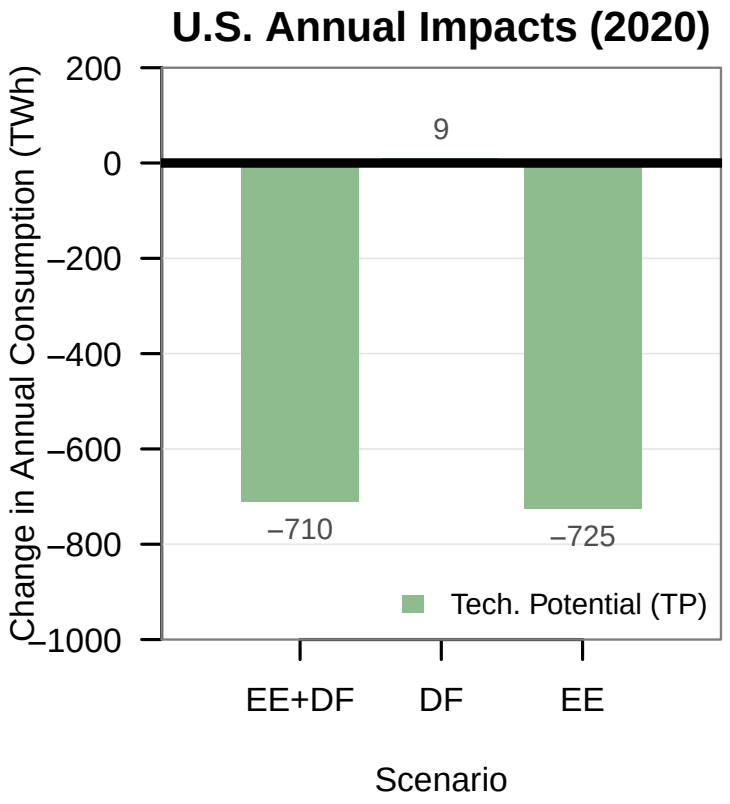

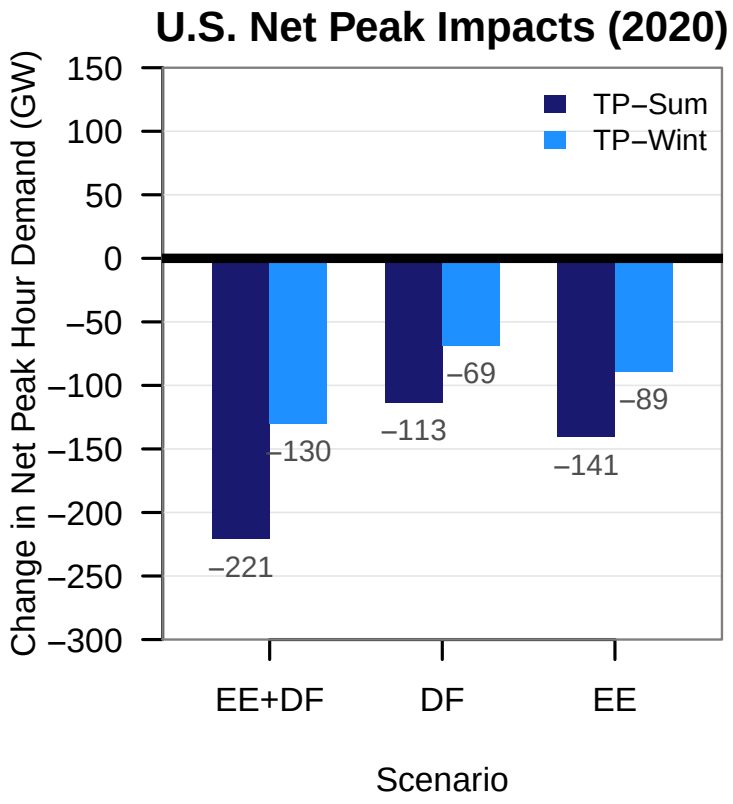

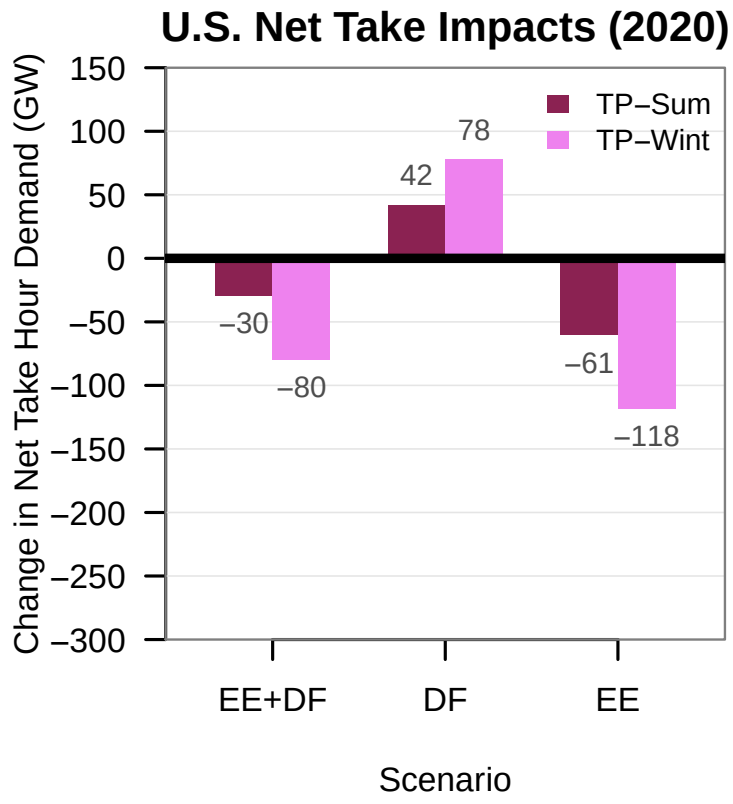

Data: Scout; Acronyms: Energy efficiency + flexibility (EE+DF), Demand flexibility (DF), Energy efficiency (EE)

Efficiency and flexibility are complementary and conflicting

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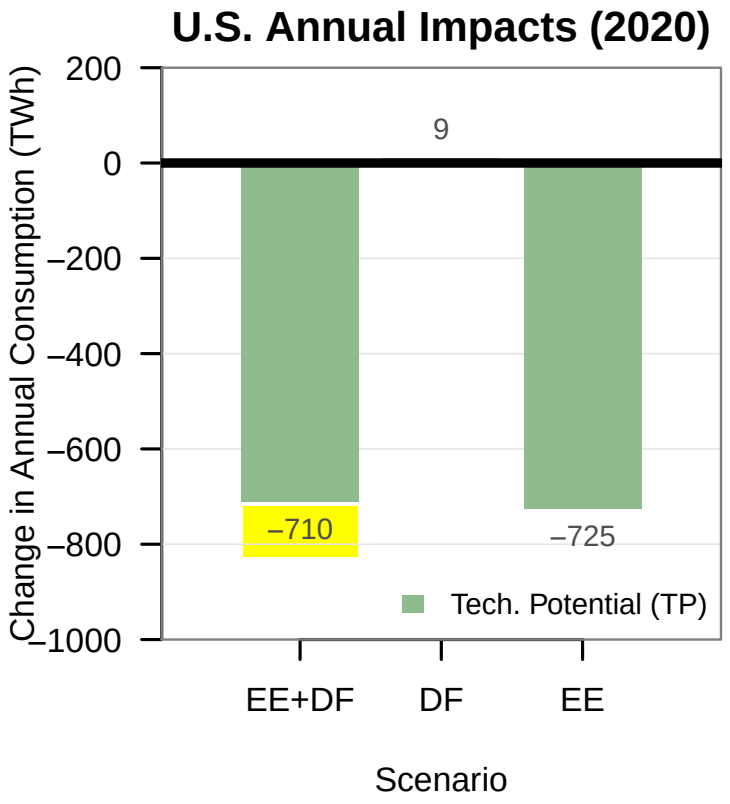

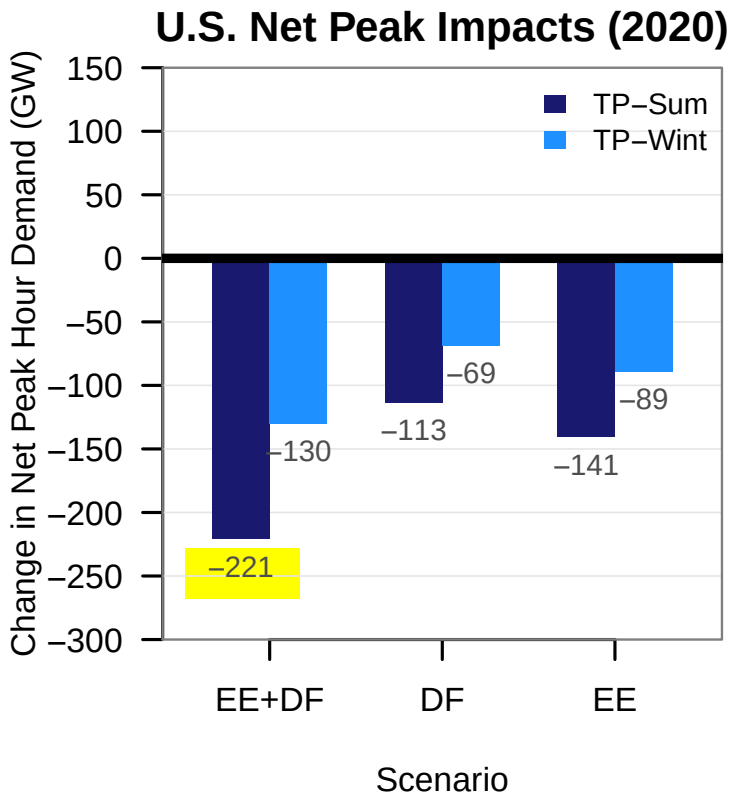

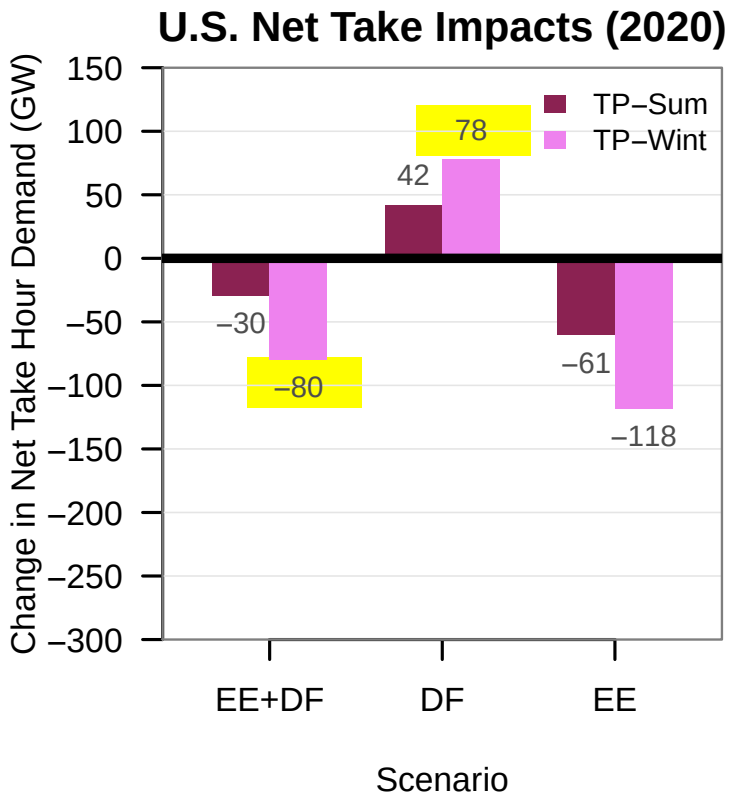

-710 TWh: *19% total U.S. electricity use in 2020*

-221 GW: *30% total summer U.S. non-coincident peak in 2020*

+78 GW: *22% of projected wind/solar capacity in 2050*
-80 GW: *Efficiency reduces opportunity to build load*

Data: Scout, EIA AEO; Acronyms: Energy efficiency + flexibility (EE+DF), Demand flexibility (DF), Energy efficiency (EE)

Residential buildings drive changes in load across metrics

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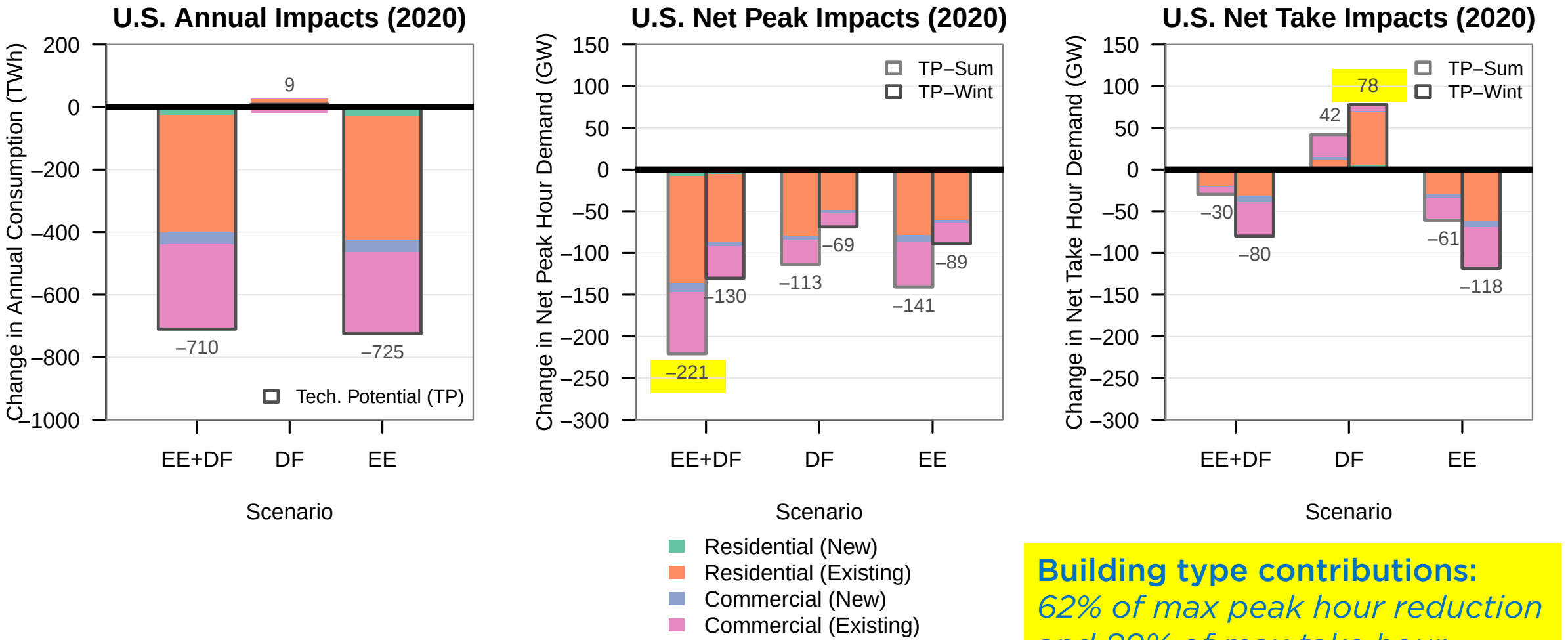

Building type contributions:
62% of max peak hour reduction and 89% of max take hour increase comes from residential

Data: Scout; Acronyms: Energy efficiency + flexibility (EE+DF), Demand flexibility (DF), Energy efficiency (EE)

Cooling drives peak reduction, heating drives load building

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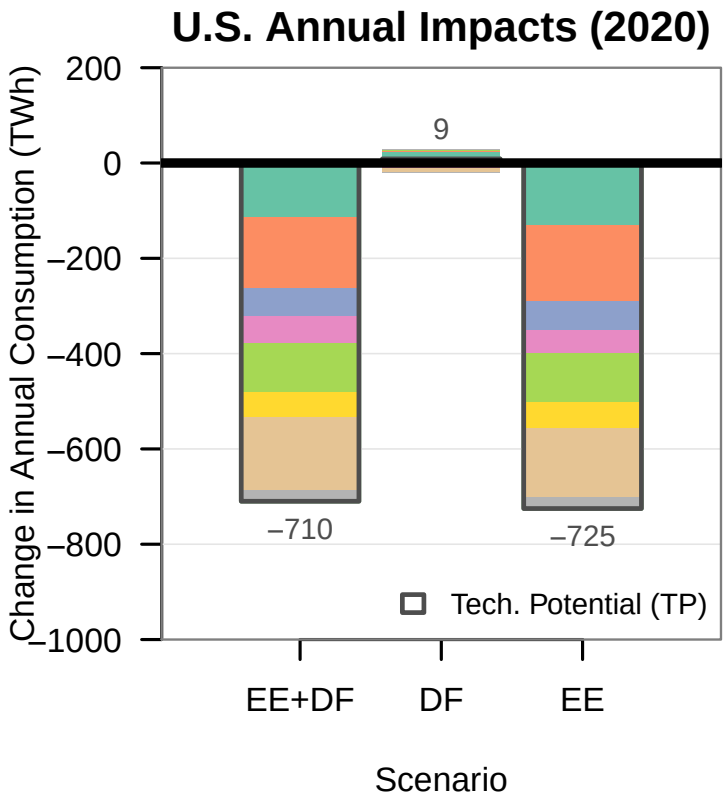

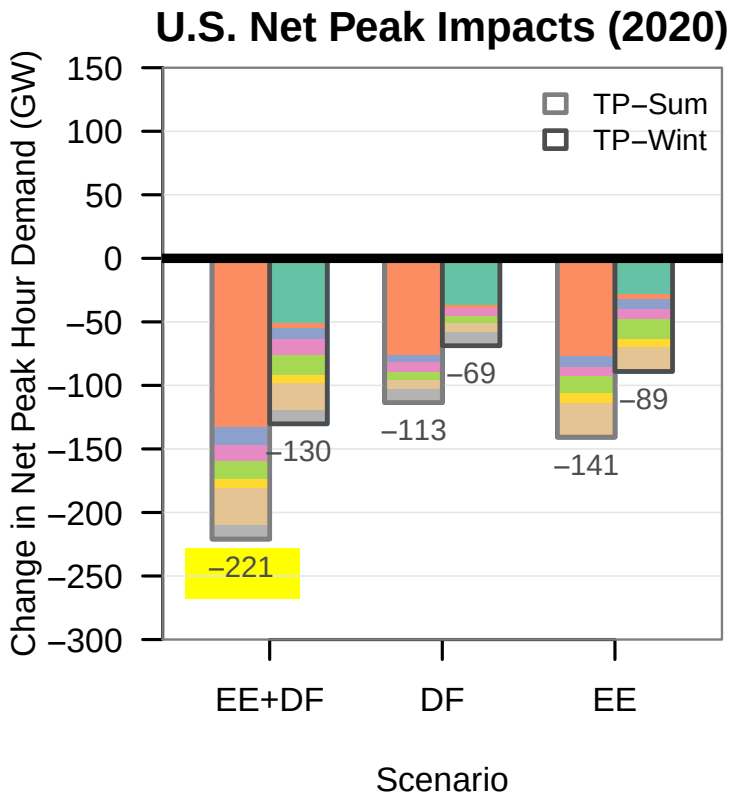

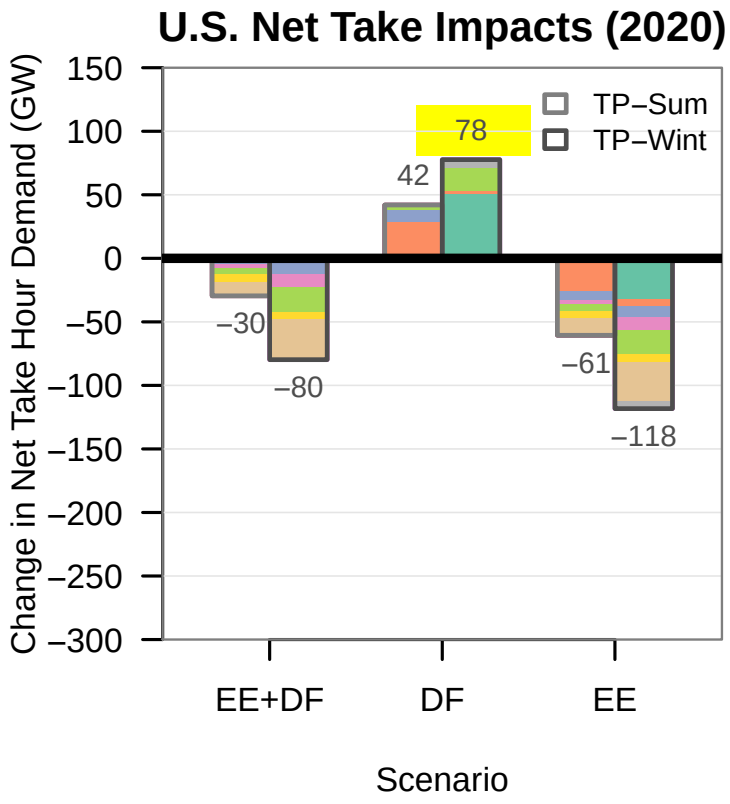

End use contributions: *67% of max peak reduction comes from cooling; 69% of max take increase comes from heating*

Data: Scout; Acronyms: Energy efficiency + flexibility (EE+DF), Demand flexibility (DF), Energy efficiency (EE)

Heating has larger influence on load building in the Southeast

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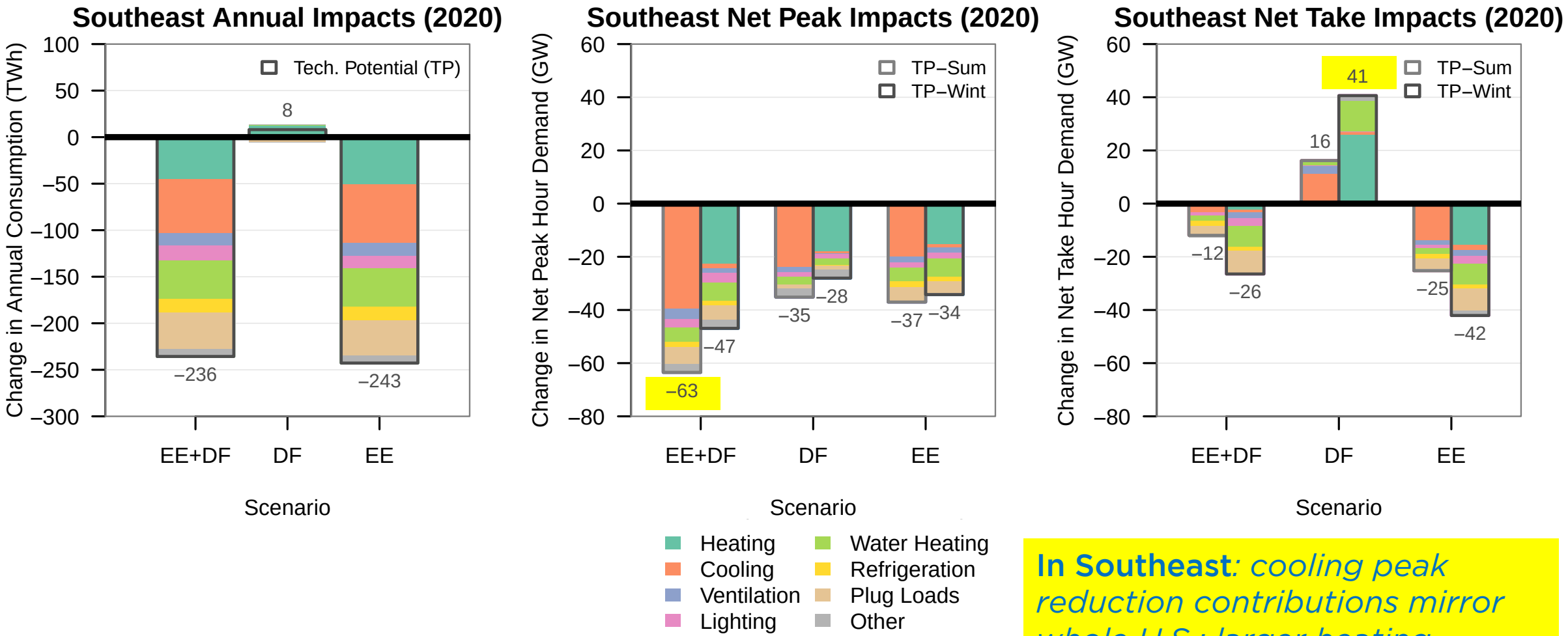

In Southeast: *cooling peak reduction contributions mirror whole U.S.; larger heating contributions to load building*

Data: Scout; Acronyms: Energy efficiency + flexibility (EE+DF), Demand flexibility (DF), Energy efficiency (EE)

Heating and cooling have lower influence in the Northeast

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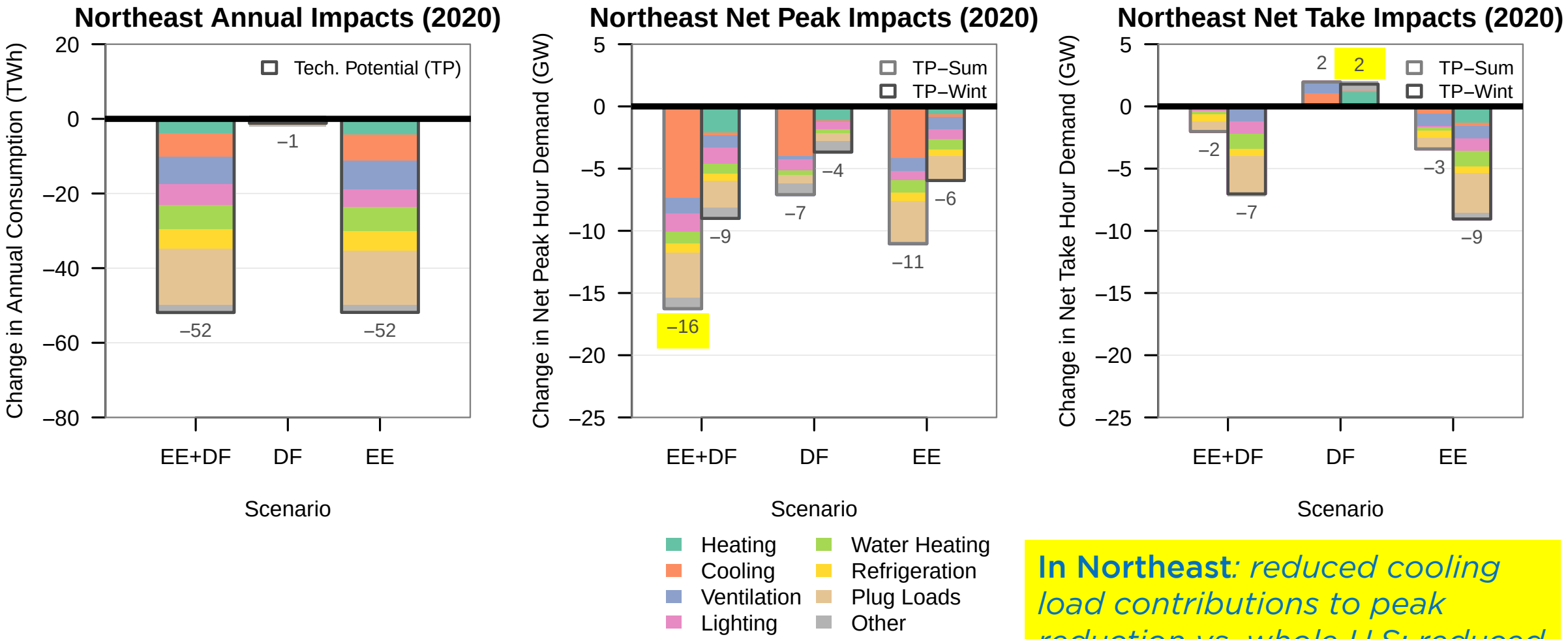

In Northeast: *reduced cooling load contributions to peak reduction vs. whole U.S; reduced load building from heating*

Data: Scout; Acronyms: Energy efficiency + flexibility (EE+DF), Demand flexibility (DF), Energy efficiency (EE)

An initial step in quantifying the building-grid resource

A quantitative framework was established for time- and location-sensitive valuation of building efficiency and flexibility measures at the national scale

- *Adapts the Scout impact analysis software to enable sub-annual assessment of U.S. building electricity use under baseline conditions and given efficiency/flexibility measure adoption*
- *Leverages ResStock (residential) and DOE Prototype Models (commercial) to develop 8760 baseline/measure building electric load shapes across 14 climates*

Initial results show a large potential peak reduction resource from buildings, interactions between efficiency and flexibility, and regional differences

- *In 2020, up to 221 GW U.S. net peak hour load (~30% total peak) could be removed by efficiency and flexibility measures, with 710 TWh annual electricity savings (19% U.S. total)*
- *Opportunities to build loads off-peak via flexibility measures (up to 78 GW hourly increase) are reduced by the addition of efficiency measures (up to 80 GW hourly decrease)*
- *The Southeast region shows the largest potential, with notable opportunities around residential heating*

Ongoing efforts document/refine key analysis assumptions, prepare the framework for wider distribution, and extend outputs to cost/emissions metrics

Thank you

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Scout: scout.energy.gov

ResStock: www.nrel.gov/buildings/resstock.html

Commercial Prototypes:
https://www.energycodes.gov/development/commercial/prototype_models

This work was authored by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308 and by The Regents of the University of California, the manager and operator of the Lawrence Berkeley National Laboratory for the DOE under Contract No. DE-AC02-05CH11231. Funding was provided by the DOE Office of Energy Efficiency and Renewable Energy Building Technologies Office.