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

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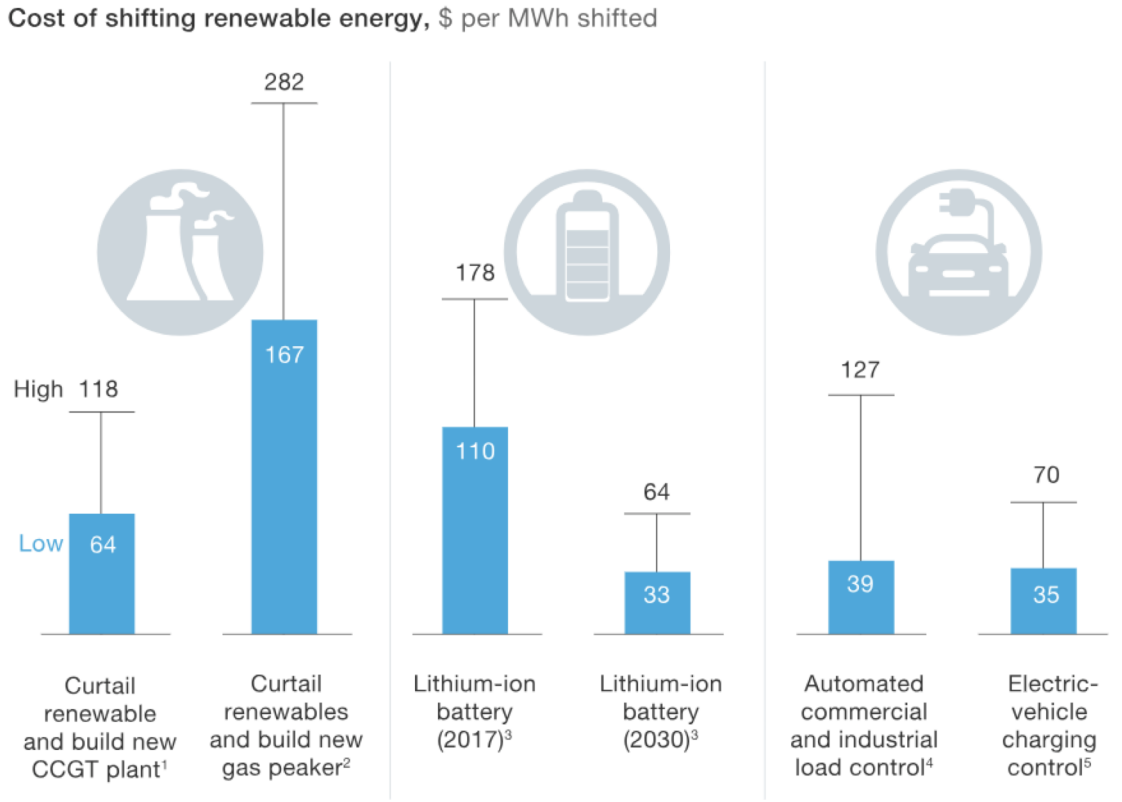
Problem: What is the U.S. grid "resource" from buildings?

Demand-side flexibility can support variable renewable electricity penetration cost-effectively, and buildings comprise 75% of U.S. electricity demand.

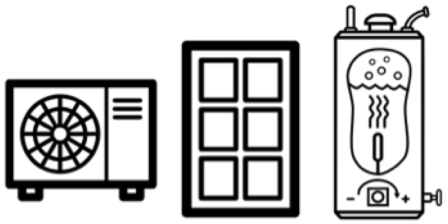
Yet, the magnitude of the potential grid resource from energy flexible buildings has not been quantified for a realistic set of emerging building technologies and operational approaches.



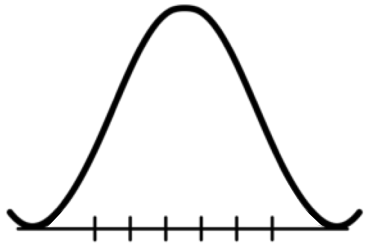
Comparison of the costs per MWh of shifting renewable energy from generation sources, and battery storage/distributed energy resources. Aggregated demand-side flexibility resources are found to be cost-effective and frequently cheaper than the generation alternative. Source: McKinsey.

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

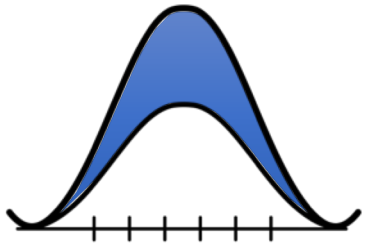
1. Define energy efficiency (EE), demand flexibility (DF), and EE + DF measure portfolios



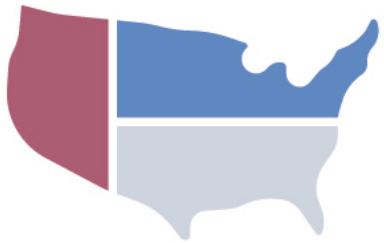
2. Develop 8760 hourly fractions of annual baseline load by climate, building type, and end use



3. Develop bottom-up EnergyPlus measure simulations and 8760 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

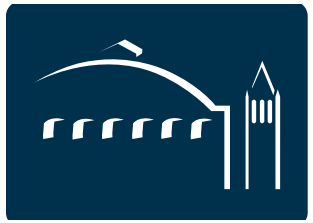
OpenStudio

Measures span major residential and commercial electric loads

ResStock

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 washer/dryer cycling, variable speed pool pump	Appliances	Shift washer/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

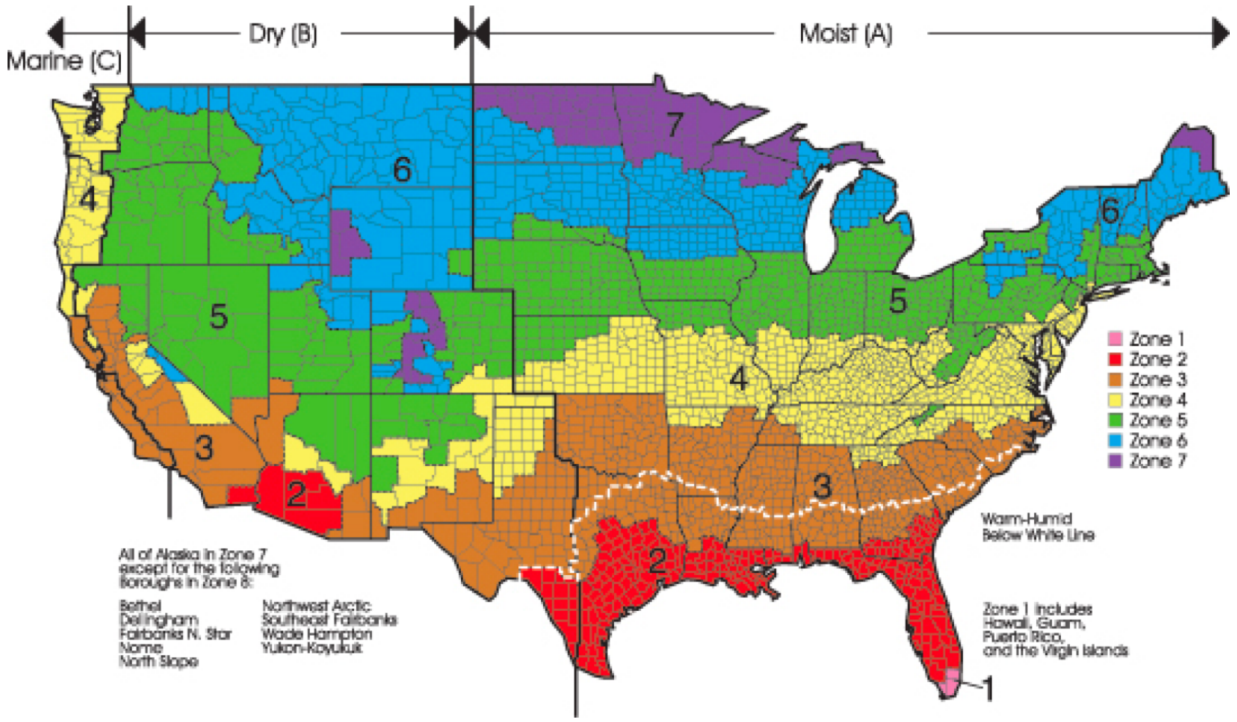


OpenStudio

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

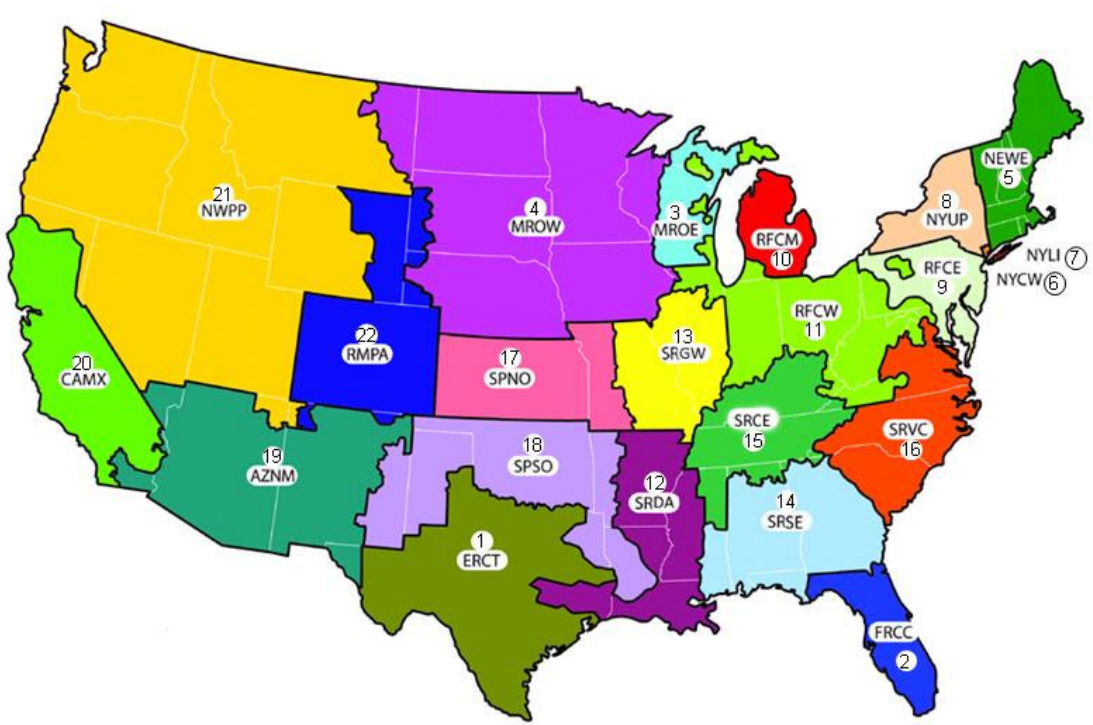
- Building-level measure operation is modeled in a representative city for 14 ASHRAE/IECC climate zones (excludes 1 and 8)
- Representative building types capture variations in loads and operational patterns
  - Residential: single family
  - Commercial: Large office, large hotel, medium office, retail,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



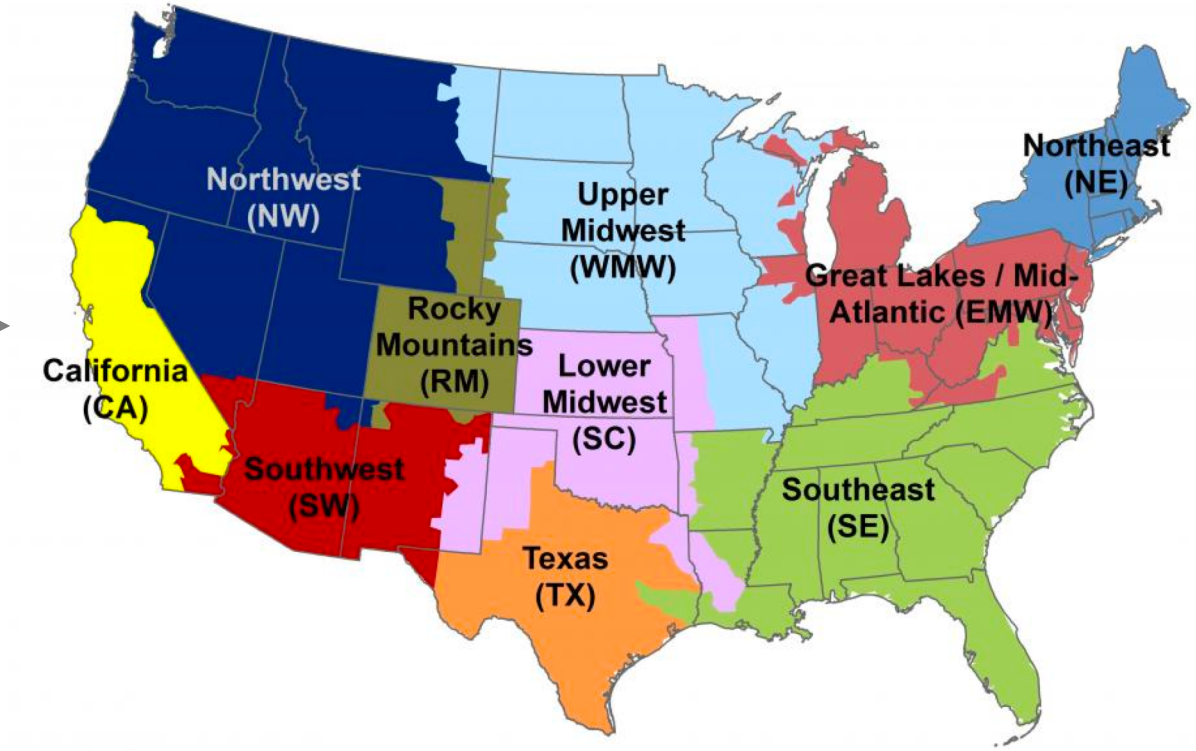
ASHRAE/IECC climate zones

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

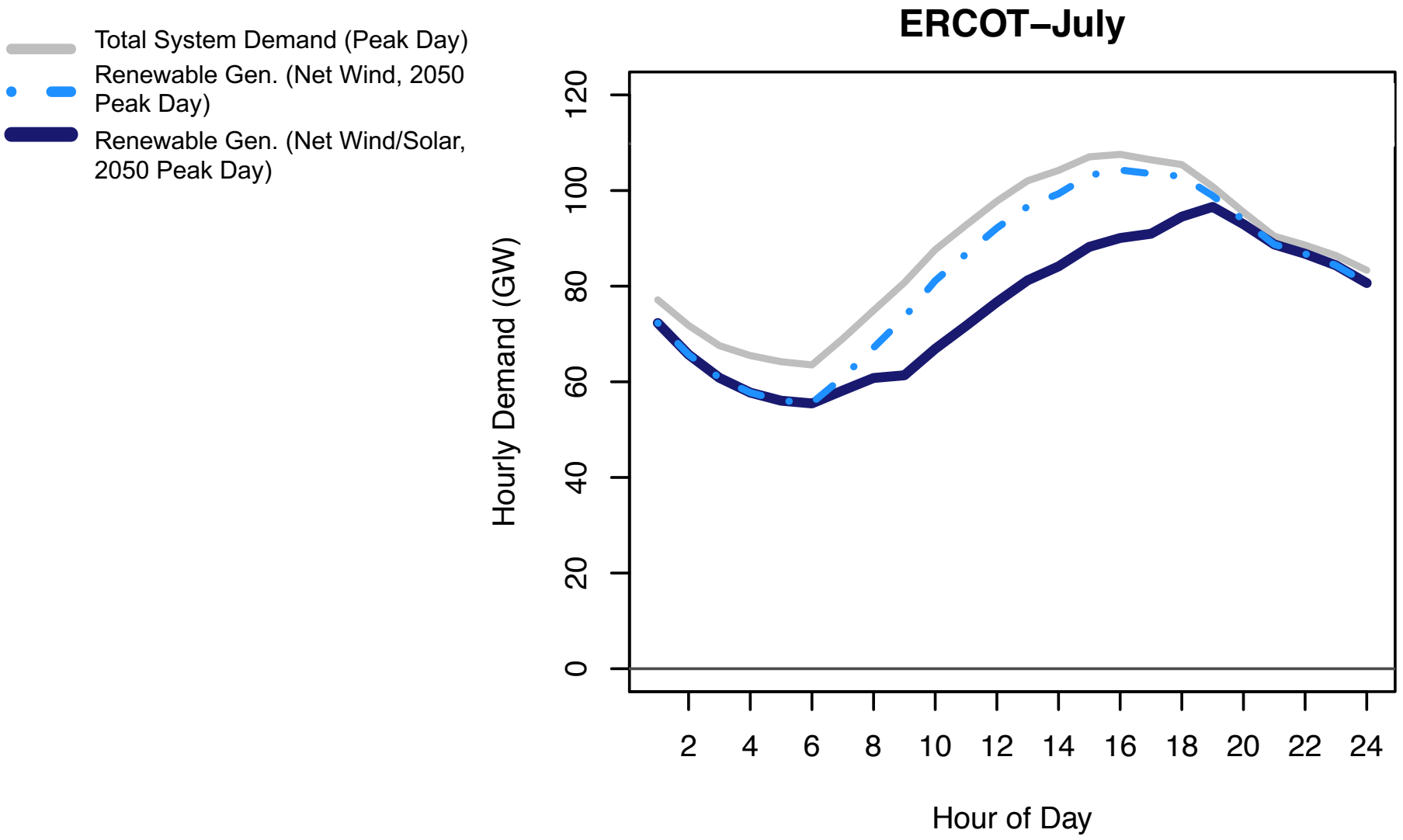


U.S. EIA EMM regions



U.S. EPA AVERT regions

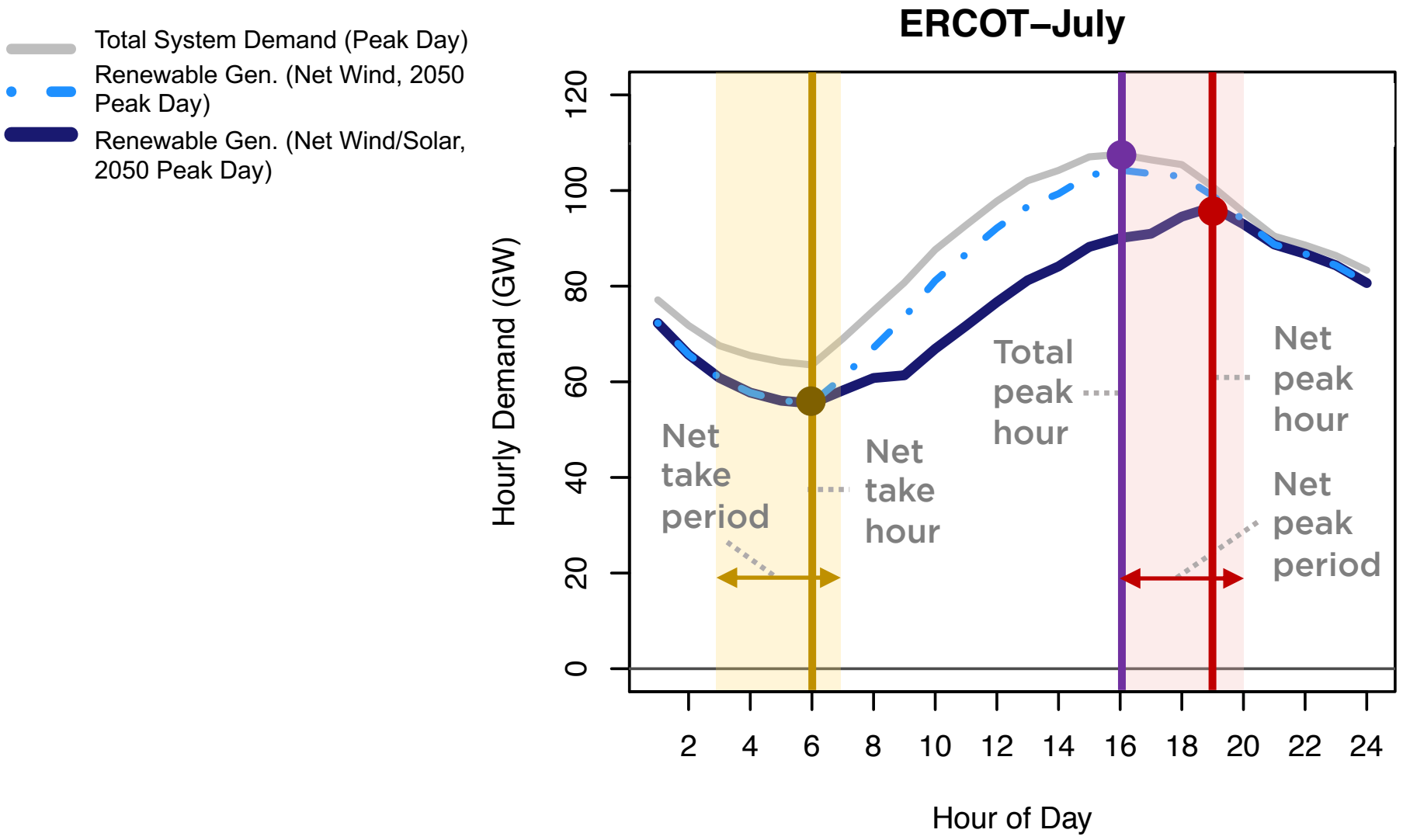
Measures either reduce or build net system loads by time of day



- 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

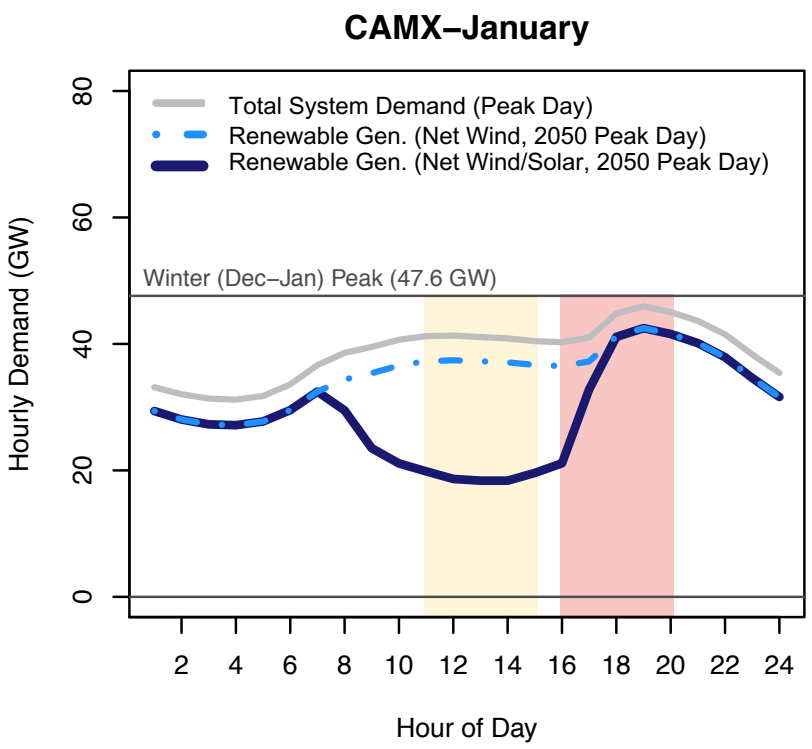


- Regional net system load shapes for the year 2050 are used as a reference for measure development (year with the highest renewable penetration levels).
- Flexibility measures are designed to remove load during net peak periods and build load during net take periods, flattening the net load shape.

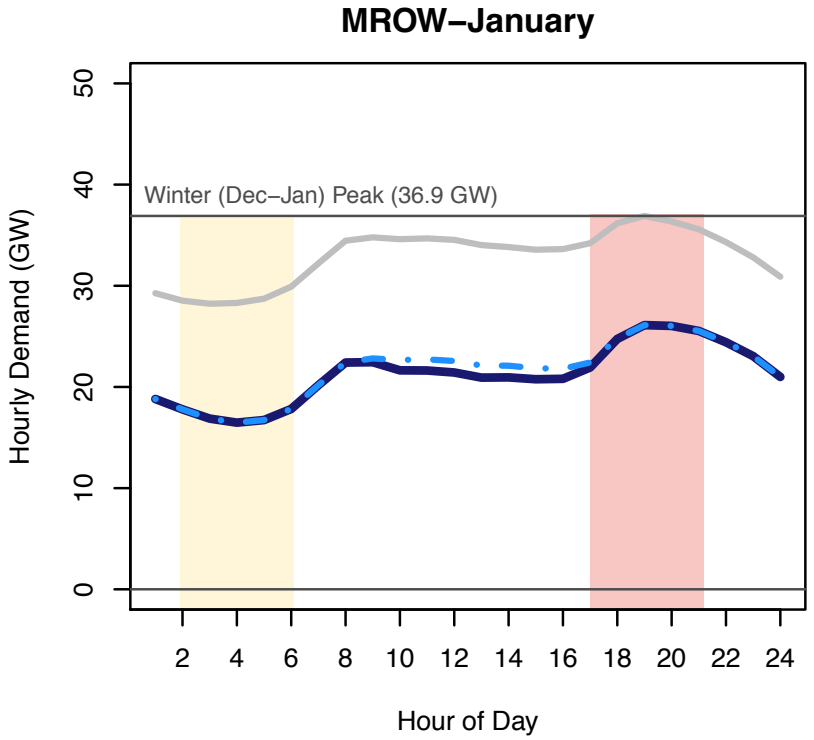
Data: EIA EMM, projection year 2050

Net load shape typologies vary by utility region and season

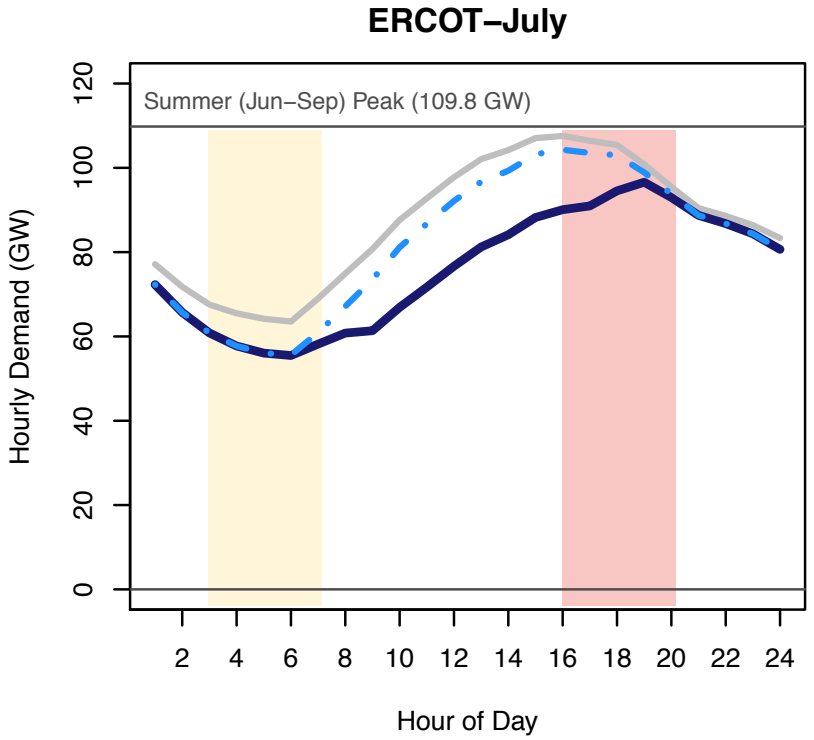
“Duck”



“Alligator”



“Hummingbird”

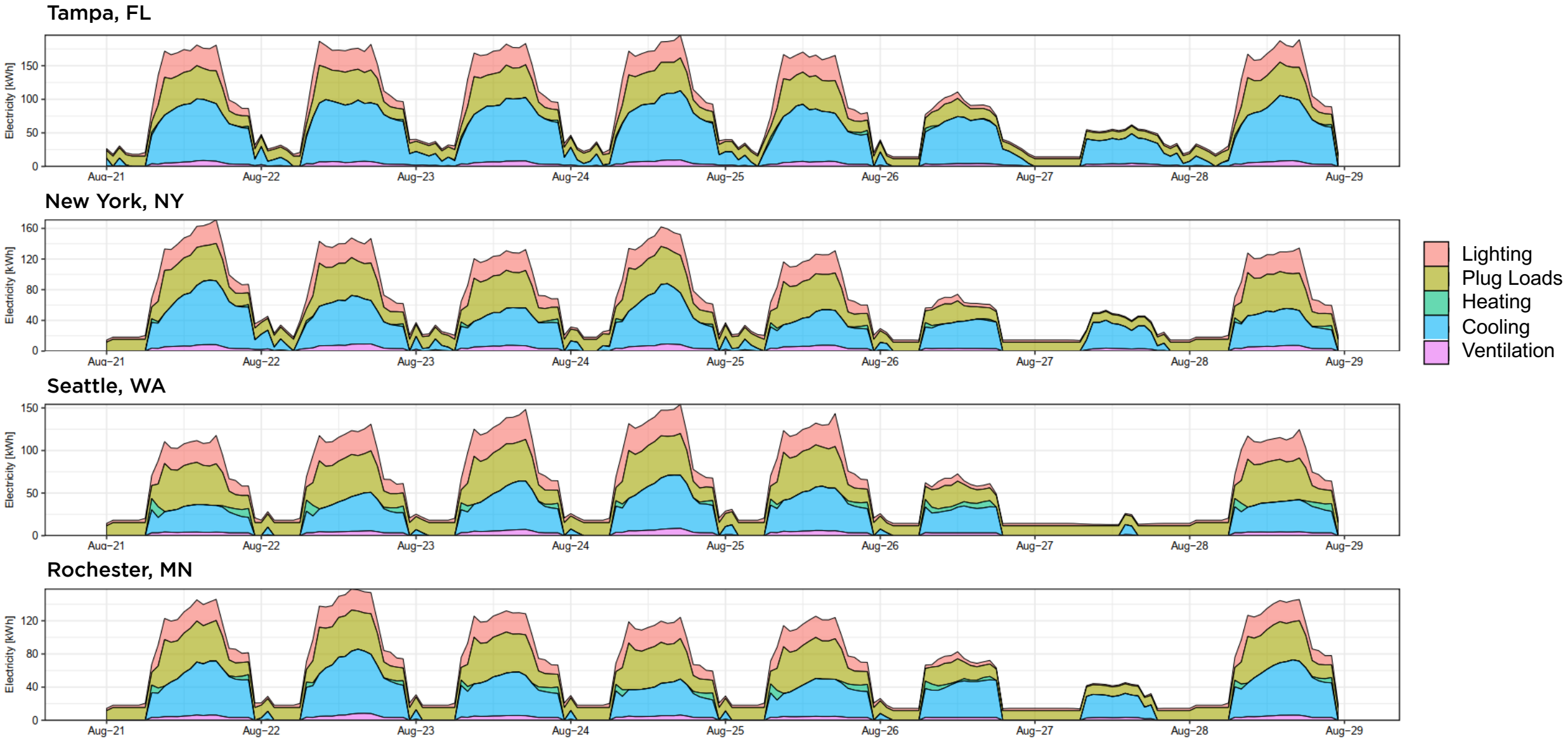


Take period (build load)

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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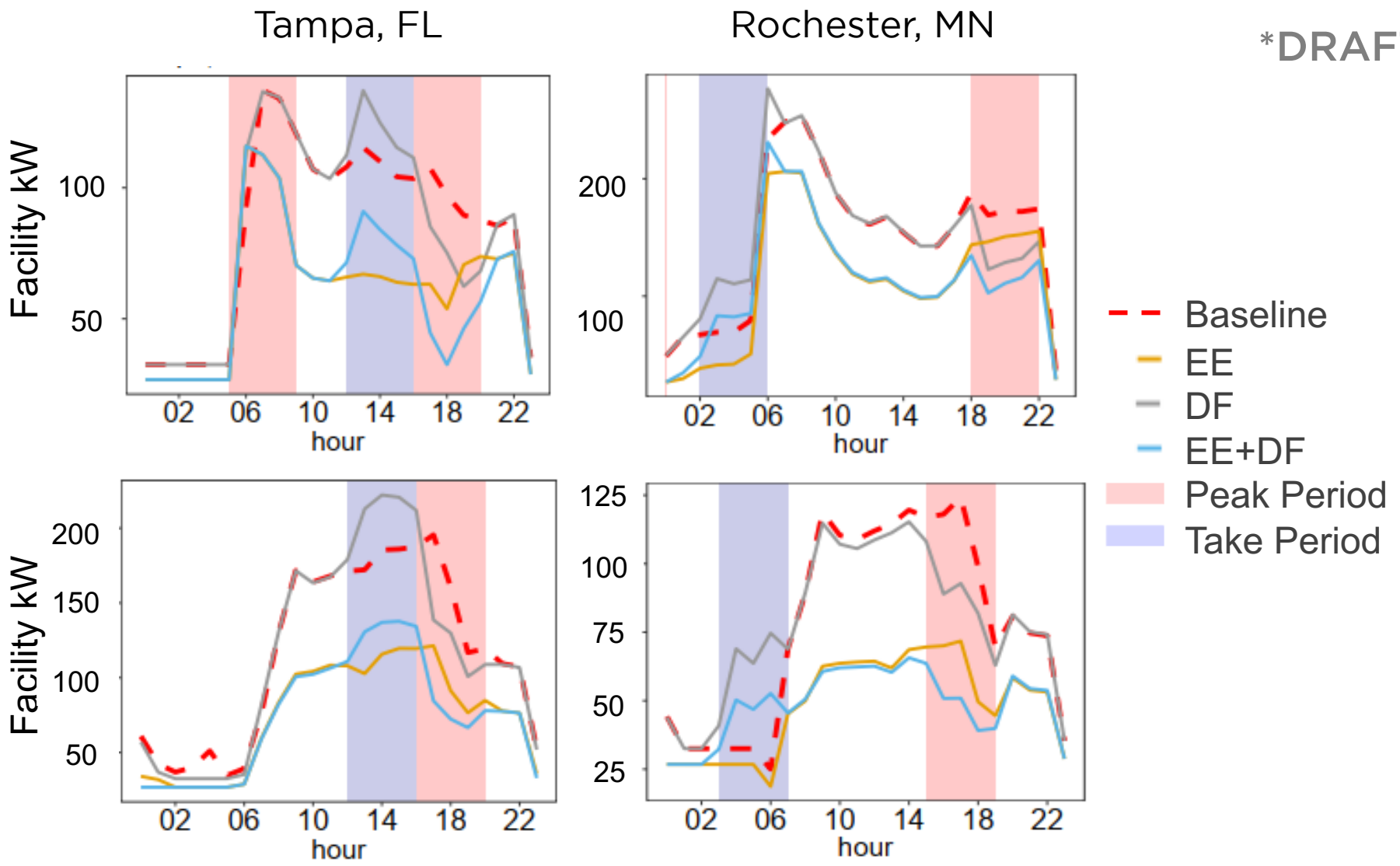
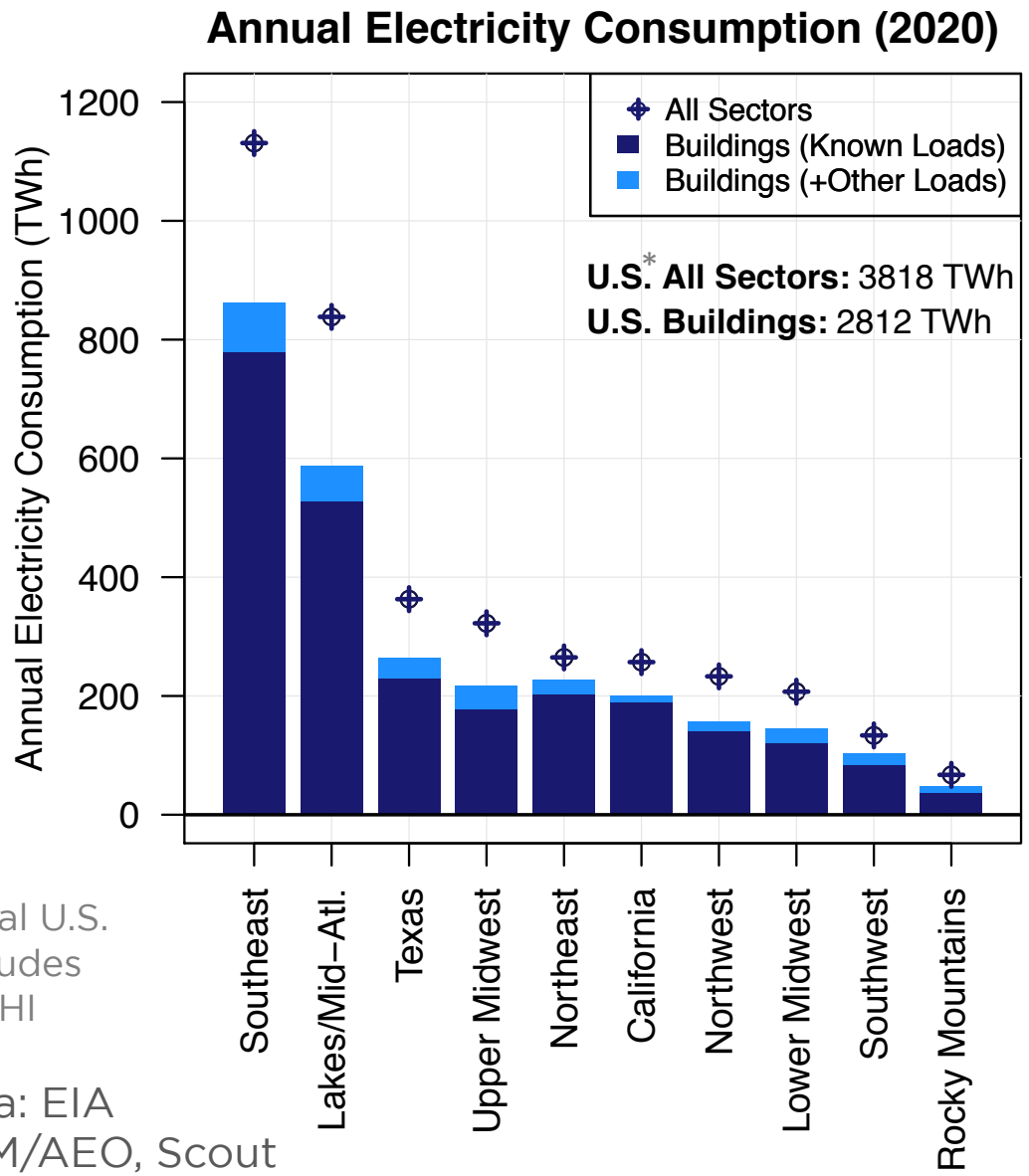
Example **winter** day
Tuesday, January 24

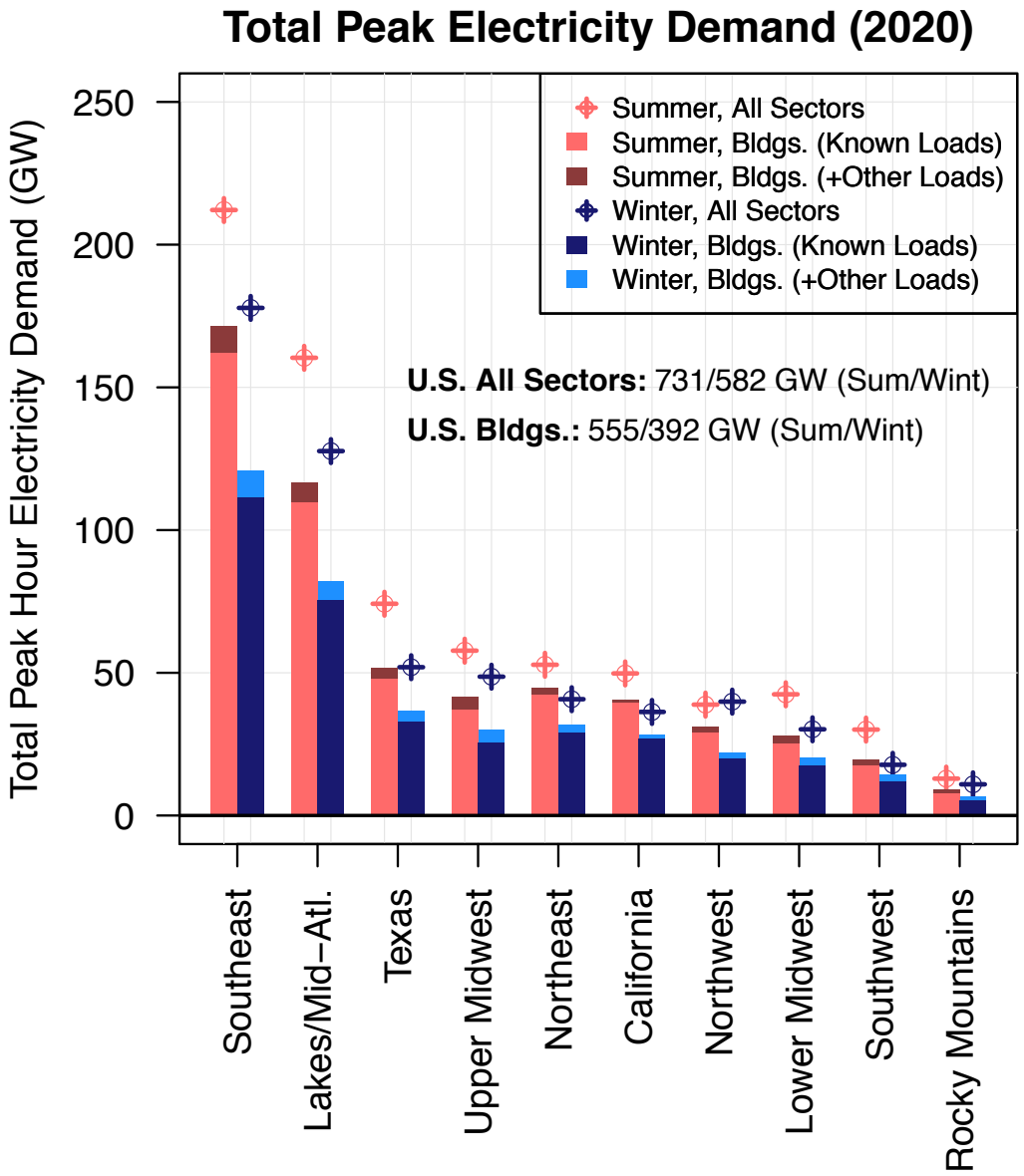
Example **summer** day
Thursday, August 24



Data sources: EnergyPlus/OpenStudio Commercial Prototypes with new Measure application

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





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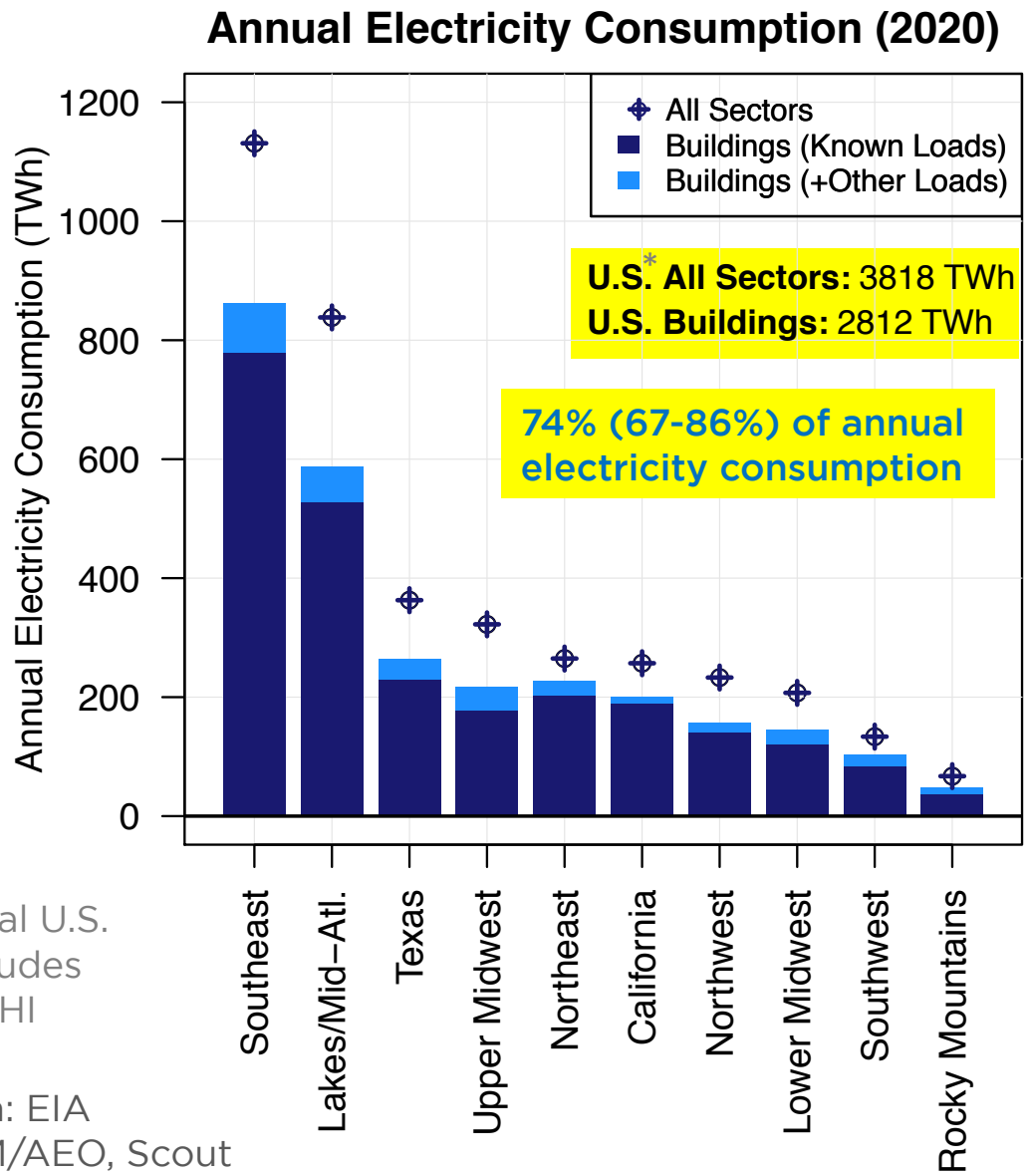
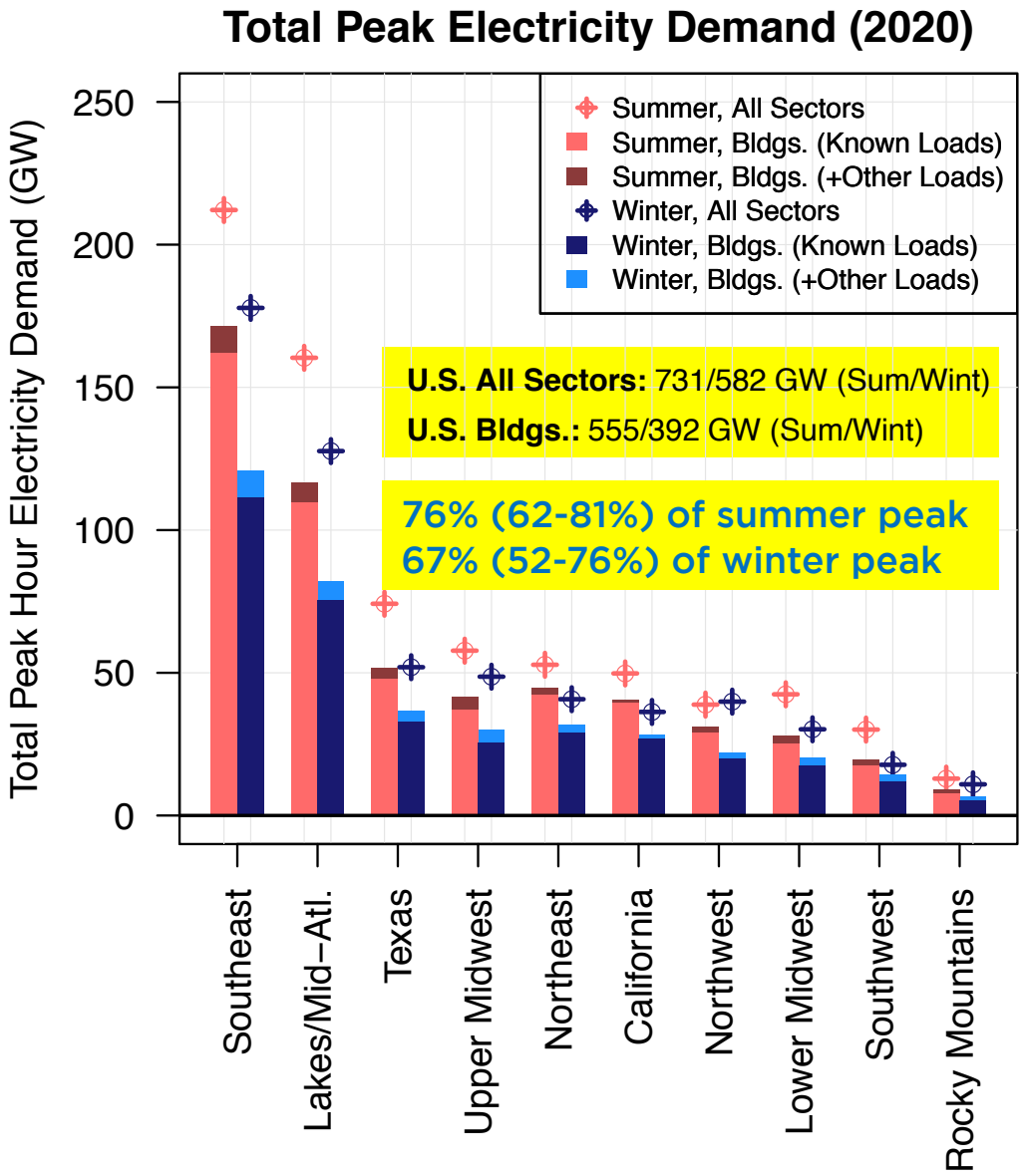
*Total U.S. excludes AK/HI

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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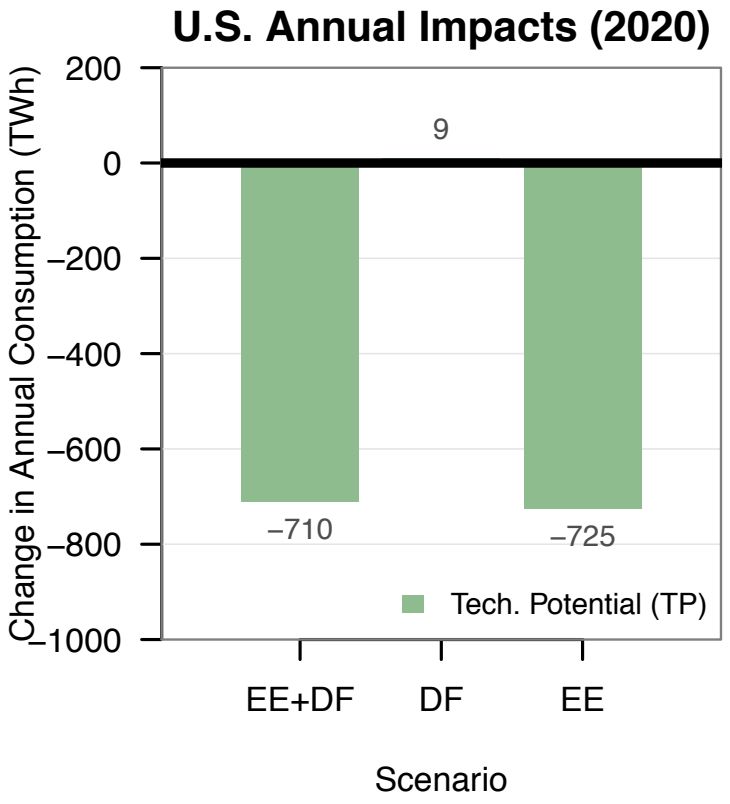

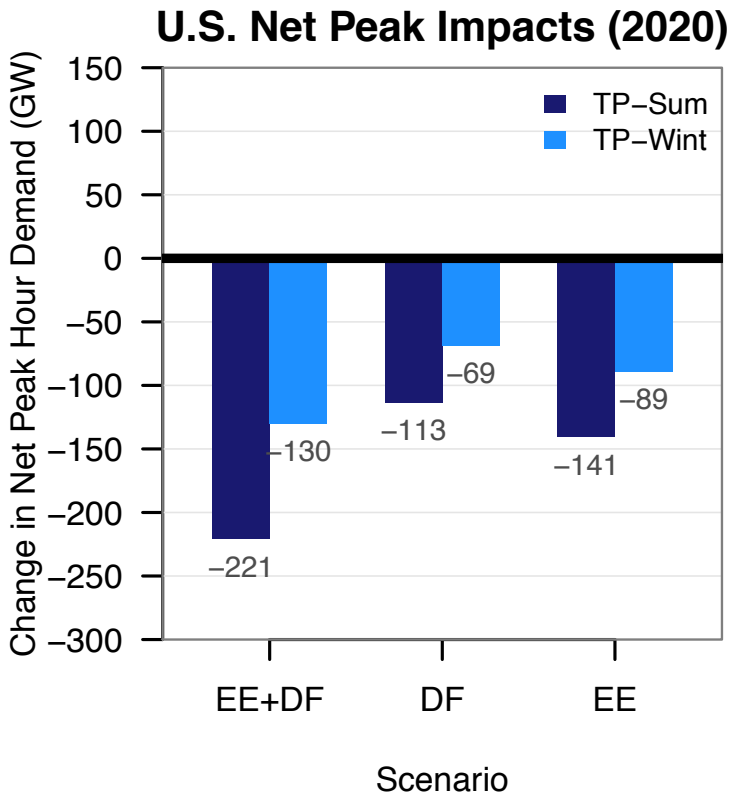

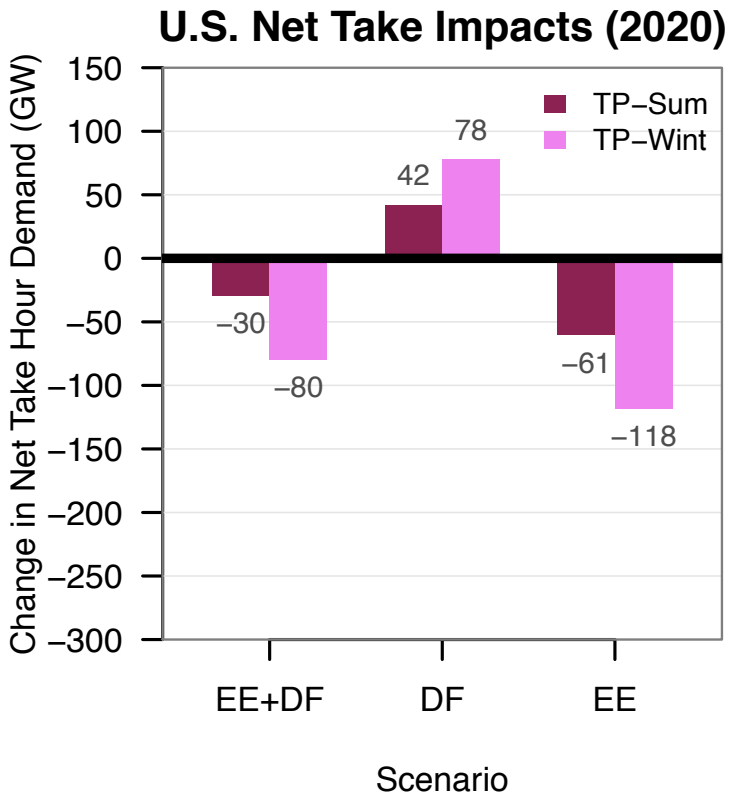

Data: Scout; Acronyms: Energy efficiency + flexibility (EE+DF), Demand flexibility (DF), Energy efficiency (EE)

Efficiency and flexibility are complementary and conflicting

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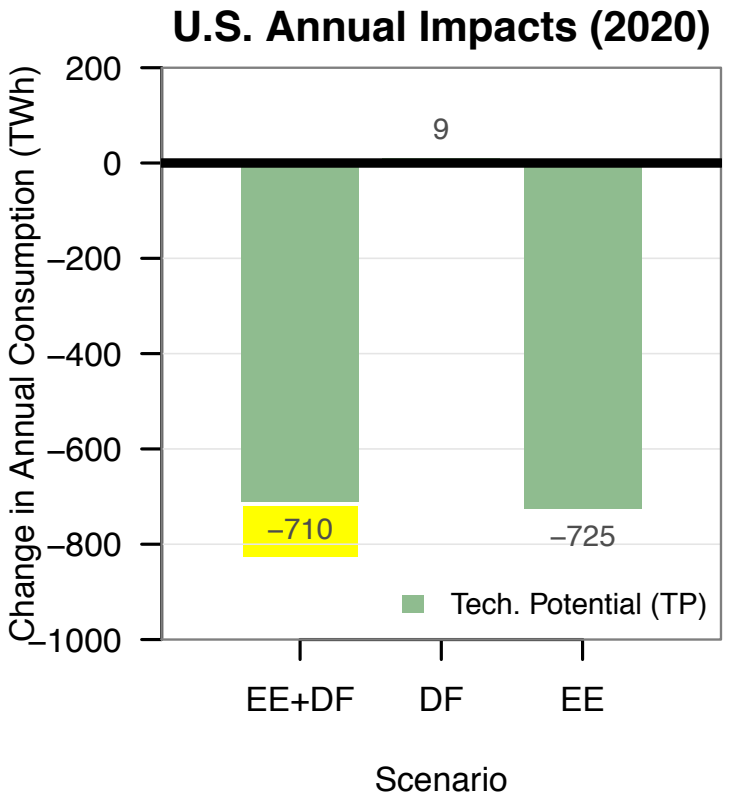

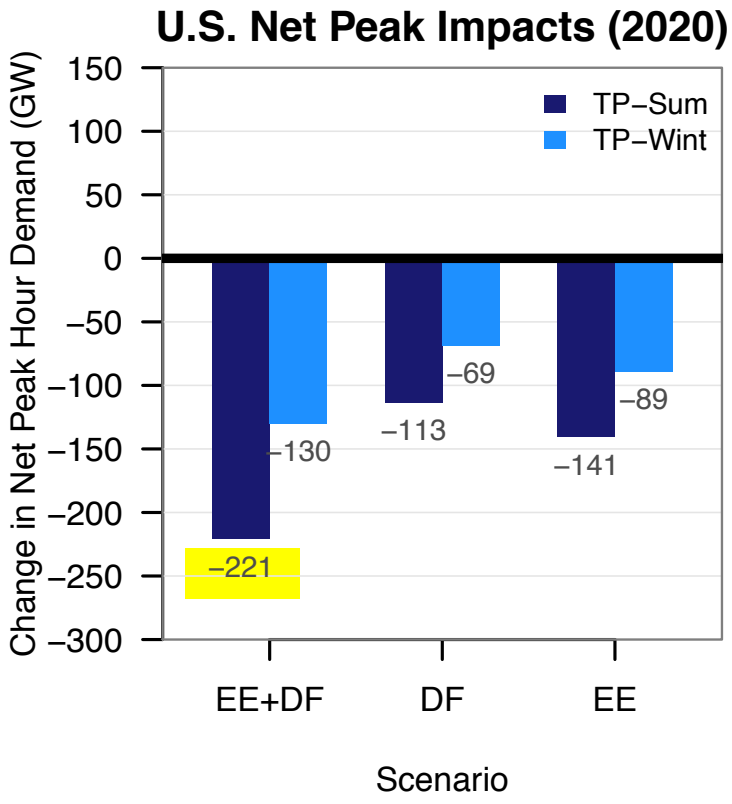

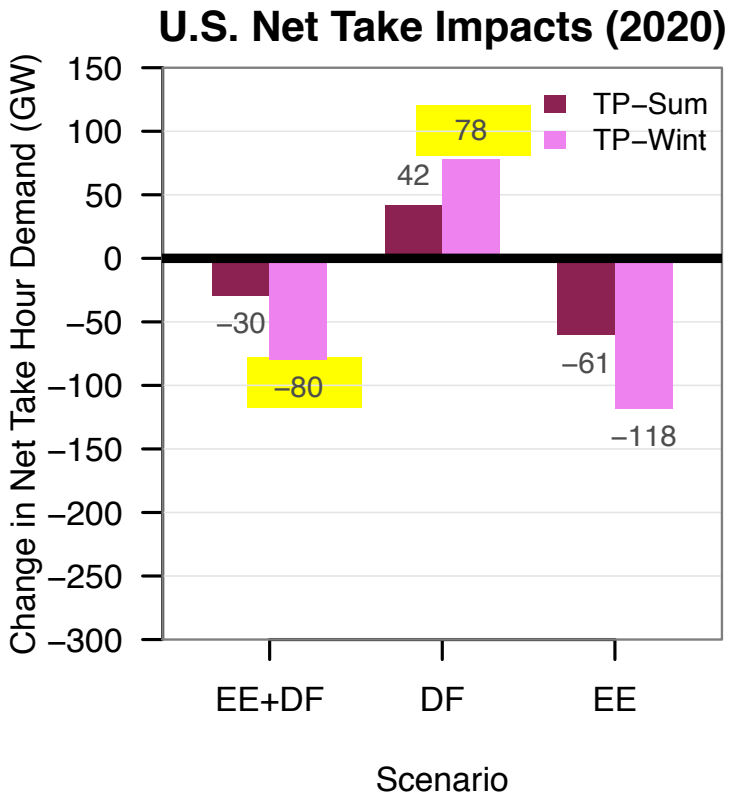

-710 TWh: 19% total U.S. electricity use in 2020

-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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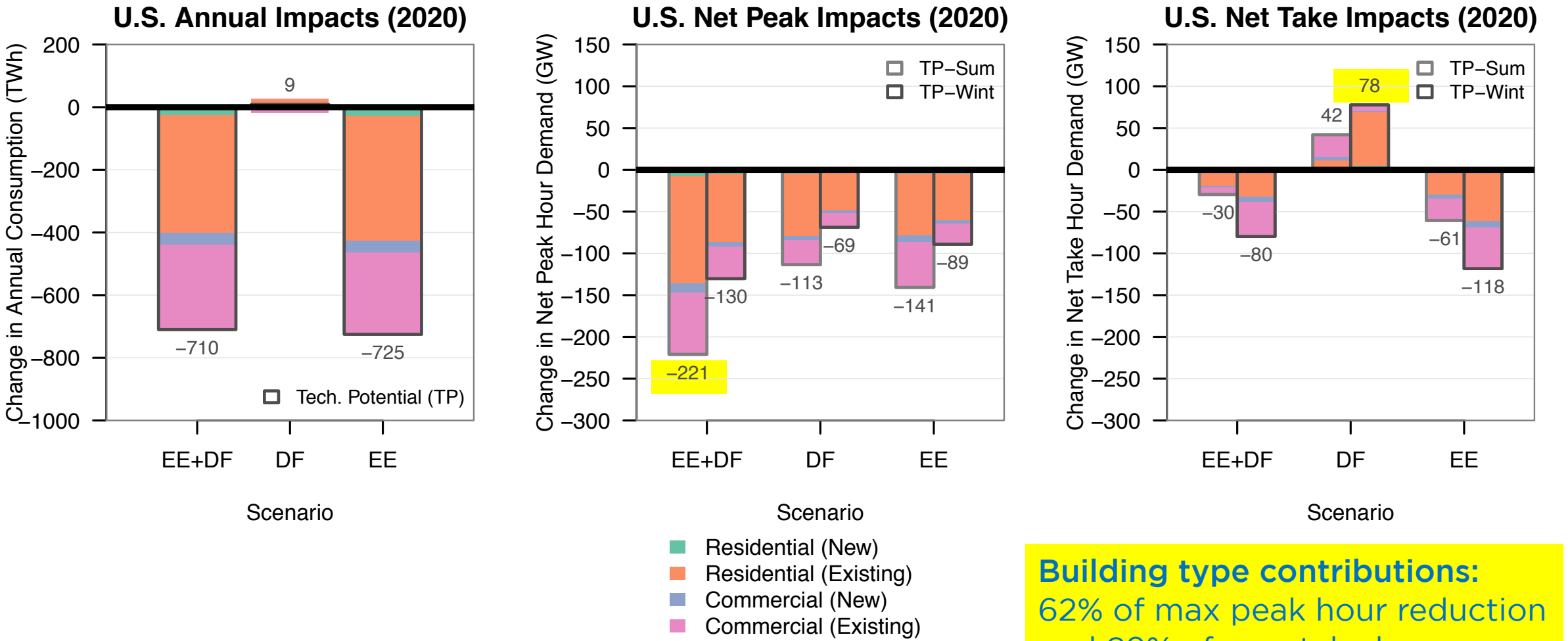

Building type contributions:
62% of max peak hour reduction and 89% of max take hour increase comes from residential

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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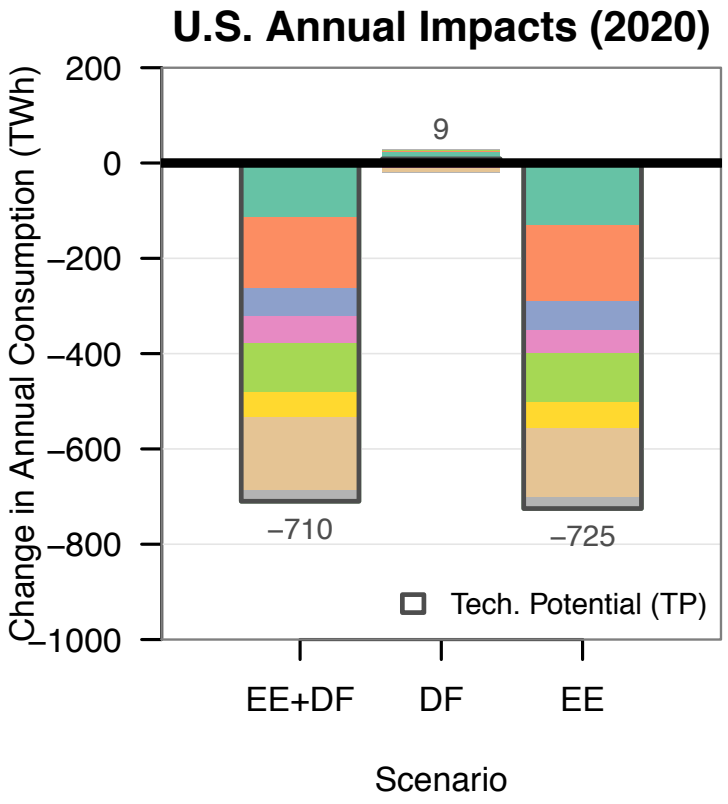

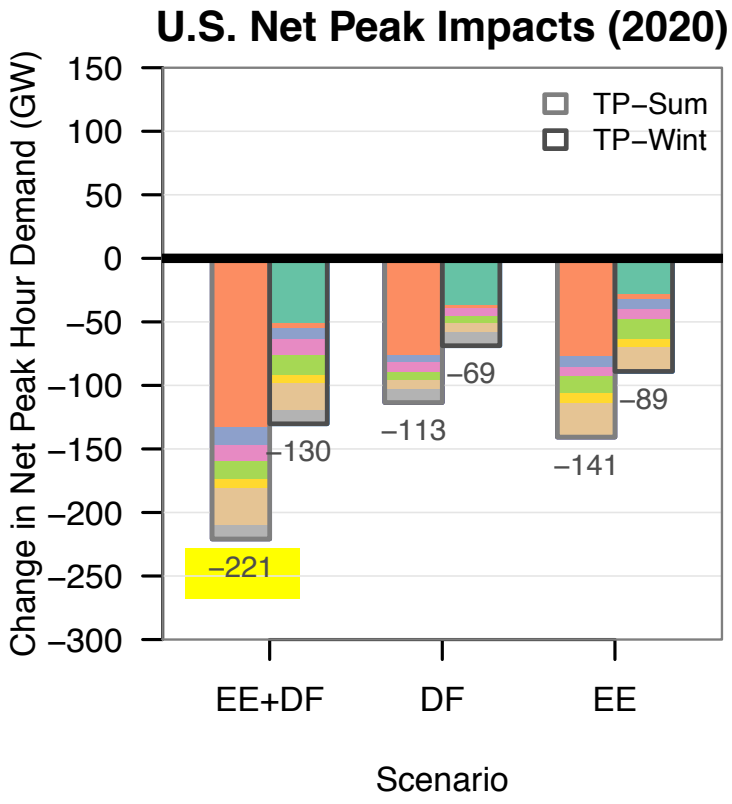

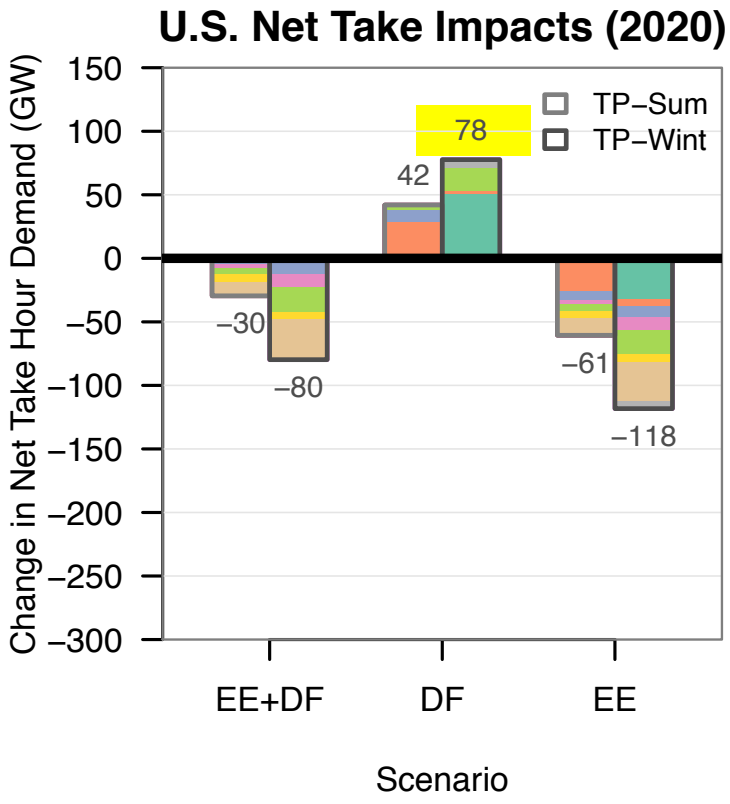

End use contributions: 67% of max peak reduction comes from cooling; 69% of max take increase comes from heating

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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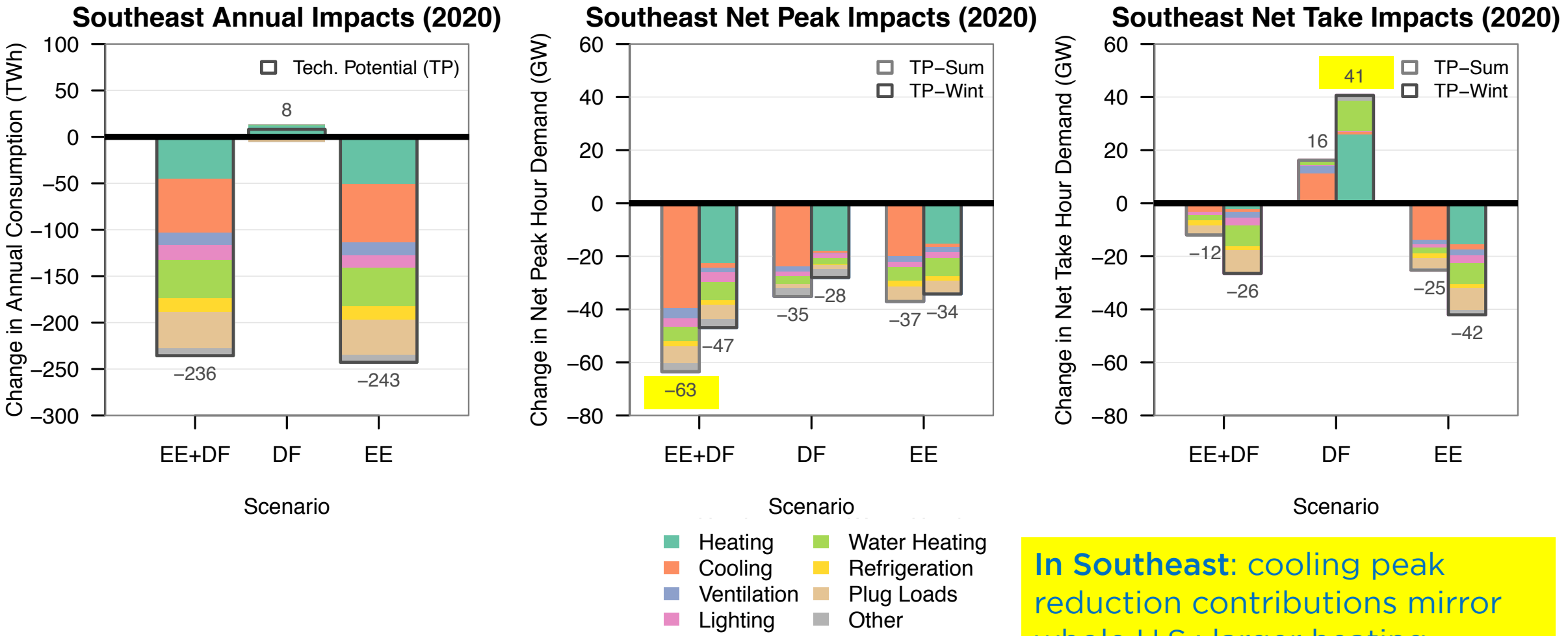

In Southeast: cooling peak reduction contributions mirror whole U.S.; larger heating contributions to load building

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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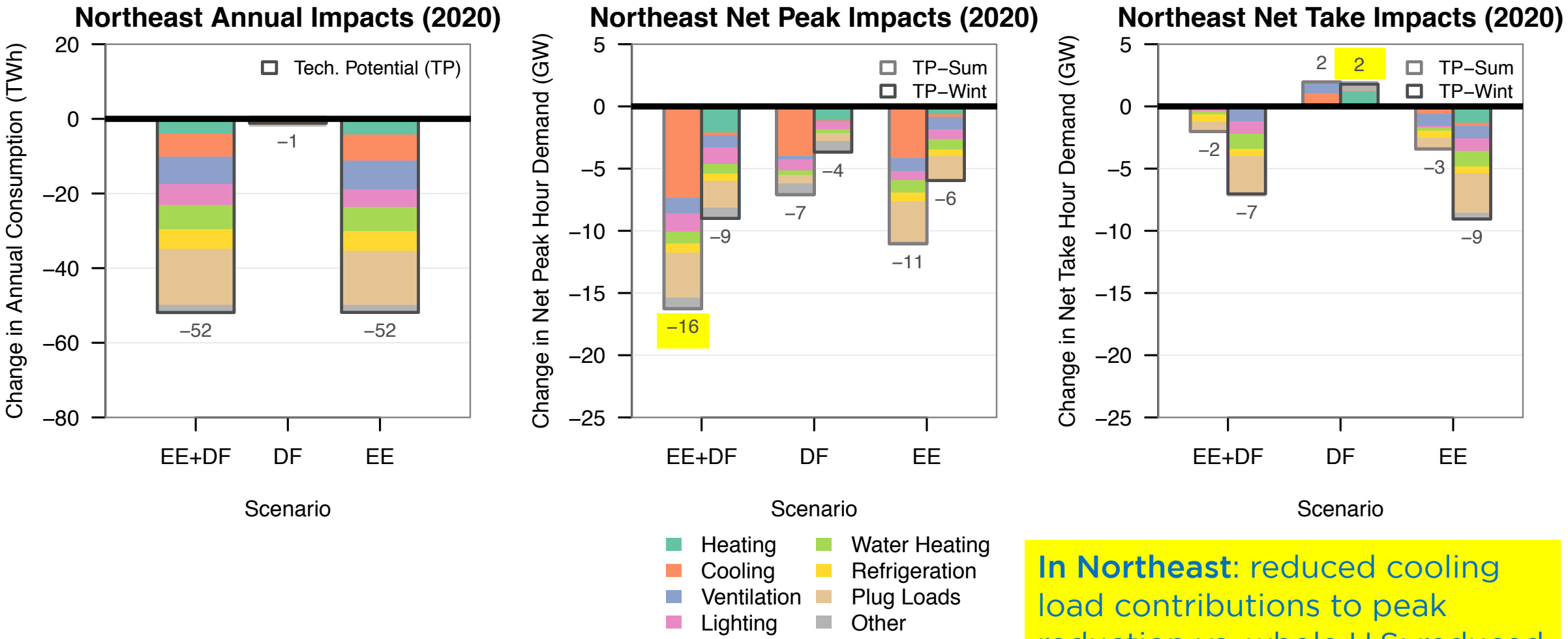

In Northeast: reduced cooling load contributions to peak reduction vs. whole U.S; reduced load building from heating

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

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