End-use Load Profiles for the U.S. Building Stock

Technical Advisory Group Meeting #10

April 21, 2021

NREL/PR-5500-79108

Natalie Mims Frick, LBNL

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Logistics

- We are recording the webinar and breakout groups.
- Because of the large number of participants on the phone, please keep yourself muted during presentations.
- Please use the chat box to send us clarifying questions during presentations. You can chat or unmute yourself to ask a question during our designated discussion time.
- Links to the slides are in the chat box.

Today’s agenda

	Mountain Time
Welcome	10:00 - 10:05
Calibration progress summary	10:05 - 10:25
Residential calibration update	10:25 - 11:10
Breakout room 1: Deep dive on residential calibration Breakout room *2:* Project recap	11:10 – 11:45
Break	11:45 – 11:50
Breakout room 1: A method for developing general load profiles for industry Breakout room 2: Cambium: a public dataset of hourly marginal carbon emissions and avoided cost metrics for the electric sector through 2050.	11:50 - 12:25
Breakout room 1: Building electrification load modeling panel Breakout room 2: Distributed PV Adoption Modeling with dGen	12:25 - 1:00

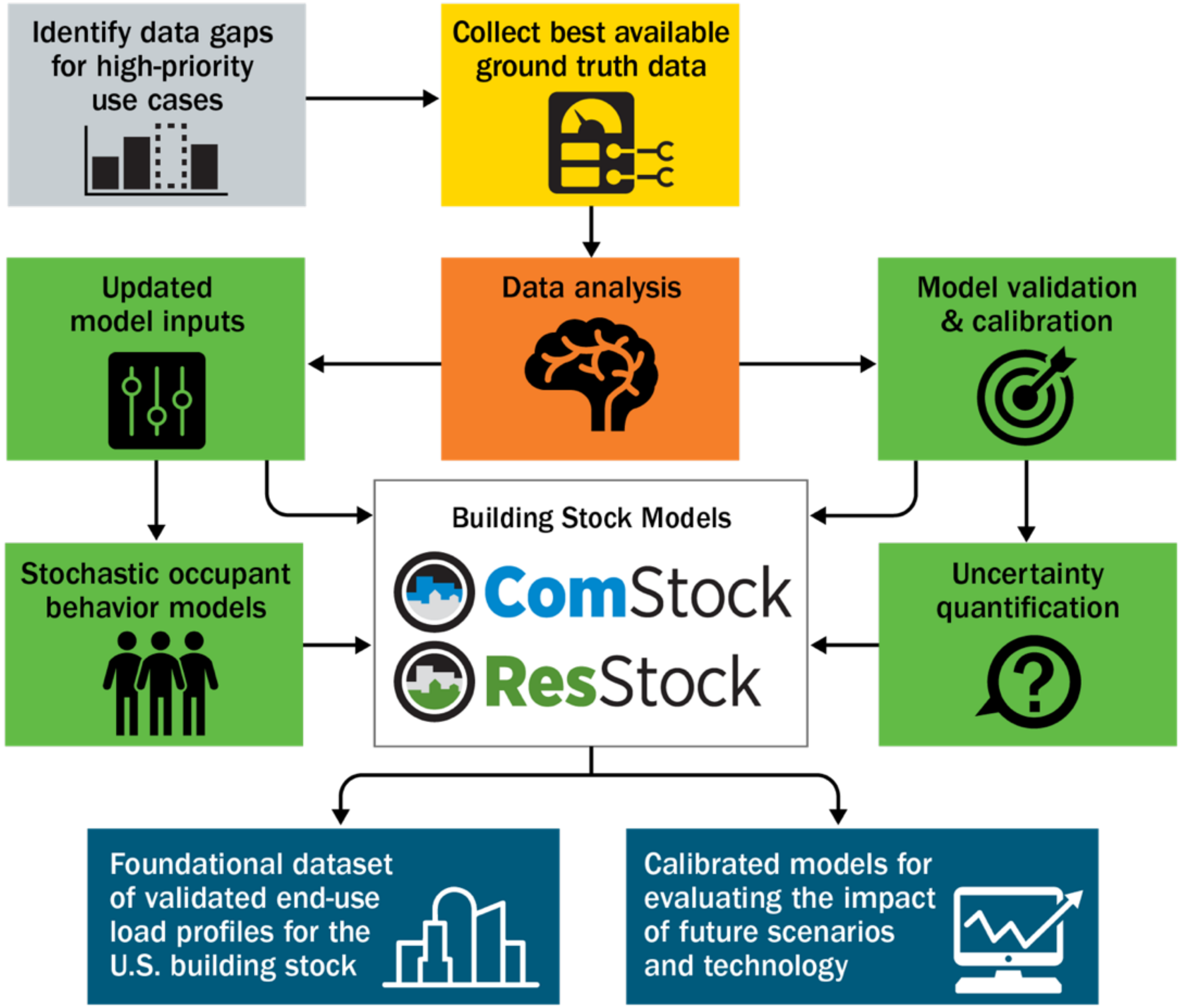
Project Overview

Hybrid approach combines
best-available ground-truth data—

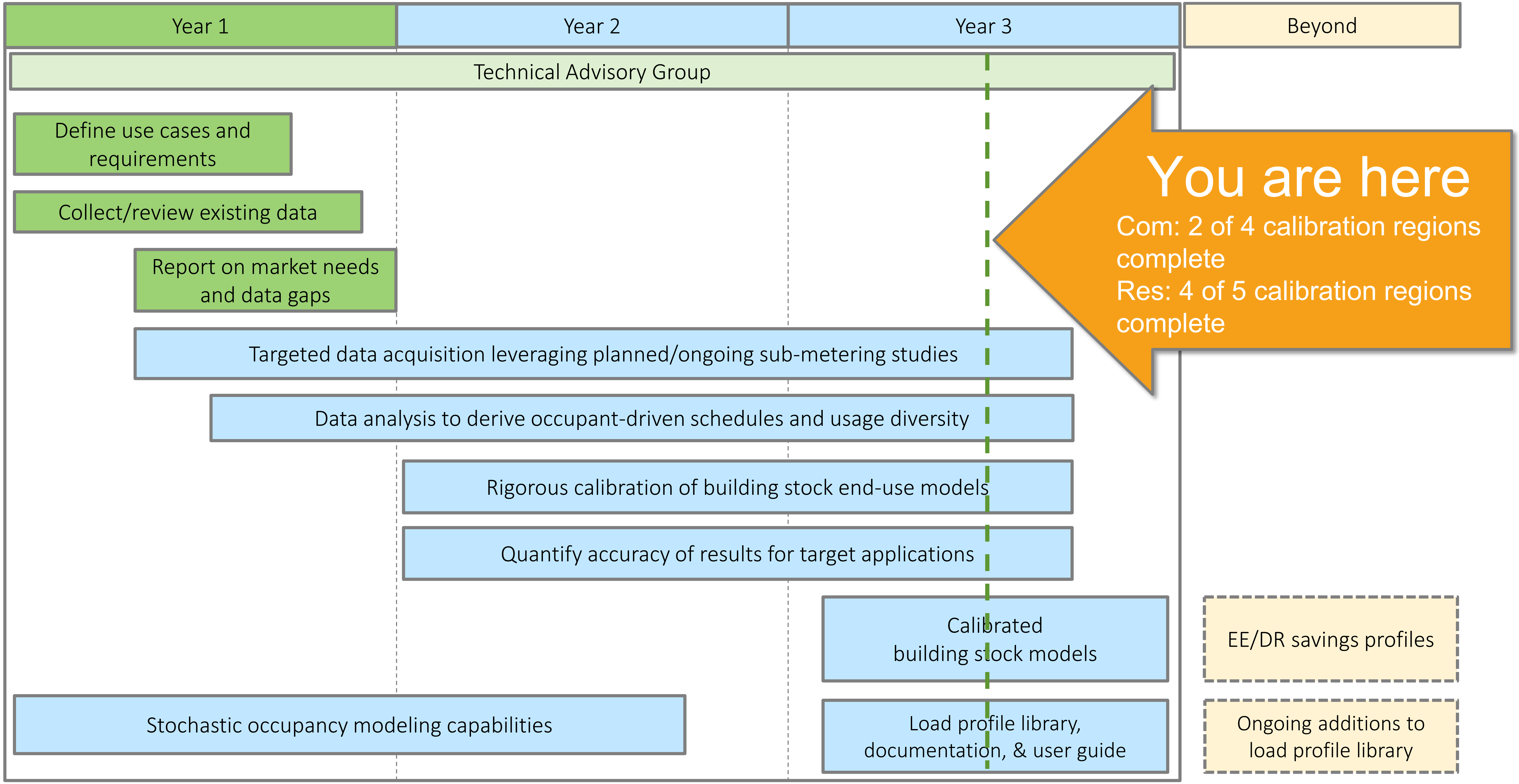
- submetering studies,
- whole-building interval meter data, and
- other emerging data sources

—with the reach, cost-effectiveness, and granularity of physics-based and data-driven building stock modeling capabilities

The novel approach delivers a nationally-comprehensive dataset at a fraction of the historical cost.



Project Timeline



Summary of FY21 Final Products for End-Use Load Profiles

Published by 9/30/2021

Public Datasets
- VizStock Web Interface
- Pre-aggregated Load Profiles
- Raw Individual Building Load Profiles
- Raw Individual Building Models

Dataset Access Instructions
The project website will provide instructions on how to access and download the various dataset formats

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Completed by 9/30/2021

Webinar
Conduct public outreach webinar to TAG and other stakeholders to present project outcomes

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Drafts to DOE & TAG by 9/30/2021

Final reports published by 12/31/2021

EERE or NREL report
End-Use Load Profiles for the U.S. Building Stock: <u>Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification</u>
- Content: Detailed description of model improvements made for calibration; detailed explanation of validation and uncertainty of results
- Audience: Dataset and model users interested in technical details
- NREL lead; LBNL and ANL co-authors

EERE or LBNL report
End-Use Load Profiles for the U.S. Building Stock: <u>Applications and Opportunities</u>
- Content: Example applications and opportunities for using the dataset
  Audience: General users of datasets
- LBNL lead; NREL co-authors

Resources

Publications

- Li et al. Characterizing Patterns and Variability of Building Electric Load Profiles in Time and Frequency Domain (forthcoming)
- Bianchi et al. 2020. Modeling occupancy-driven building loads for large and diversified building stocks through the use of parametric schedules
- Parker et al. 2020. Framework for Extracting and Characterizing Load Profile Variability Based on a Comparative Study of Different Wavelet Functions
- Present et al. 2020. Putting our Industry's Data to Work: A Case Study of Large Scale Data Aggregation
- Northeast Energy Efificency Partnership (NEEP). 2020. Sharing Load Profile Data: Best Practices and Examples
- Frick et al. 2019. End-Use Load Profiles for the U.S. Building Stock: Market Needs, Use Cases, and Data Gaps
- N. Frick. 2019. End Use Load Profile Inventory
- E.Present and E. Wilson. 2019. End use load profiles for the U.S. Building Stock

Presentations and Slides

- Technical Advisory Group slides
  - LBNL and NREL site
- E. Wilson. 2020. EFX webinar
- E. Wilson. 2019. E Source interview
- E. Wilson. 2019. Peer Review presentation
- E. Present. 2019. NEEP presentation.

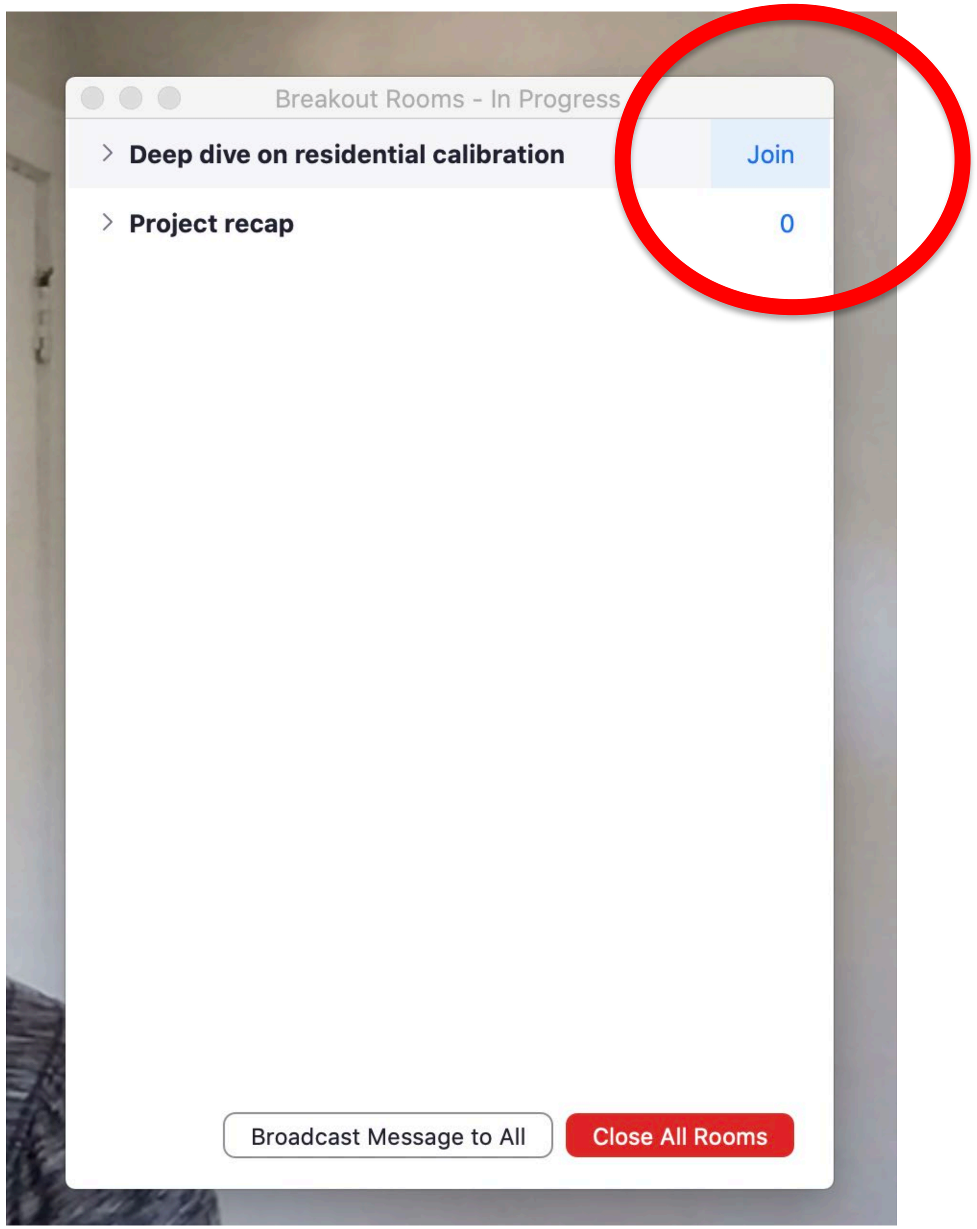
Software

- OpenStudio Occupant Variability Gem and Non Routine Variability Gem (more info at IBPSA newsletter)

Data

- First year of 15-min NEEA HEMS data available: https://neea.org/data/end-use-load-research/energy-metering-study-data

Breakout group #1: Selecting your breakout room



Room 1: *Deep dive on residential calibration*. In this breakout session we will answer questions that members have on our residential calibration. We can discuss questions pertaining to the results from our fourth residential region, past calibration results or other aspects of our residential calibration process.

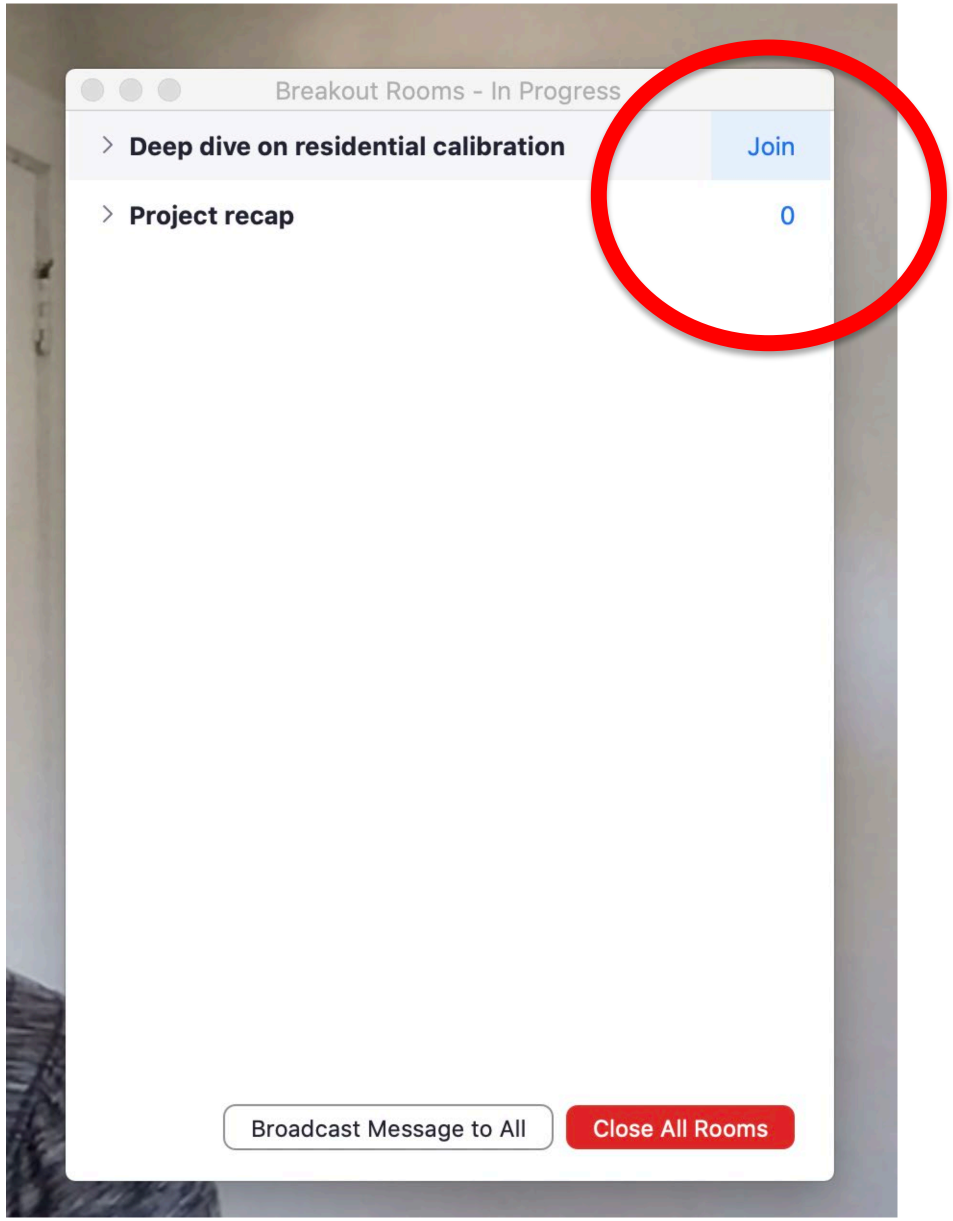
Room 2. *Project recap*. Members of the End Use Load Profile team will provide an overview of the project, our work to date and our final load profiles and models. We are offering this breakout group for members who have not been in the Technical Advisory Group for the entire project or anyone who would like a refresher on the project status and goals.

Breakout rooms will be recorded.

Break 11:45 -11:50 MT

Please rejoin us at 11:50 MT to participate in breakout group #2

Breakout group #2: Selecting your breakout room

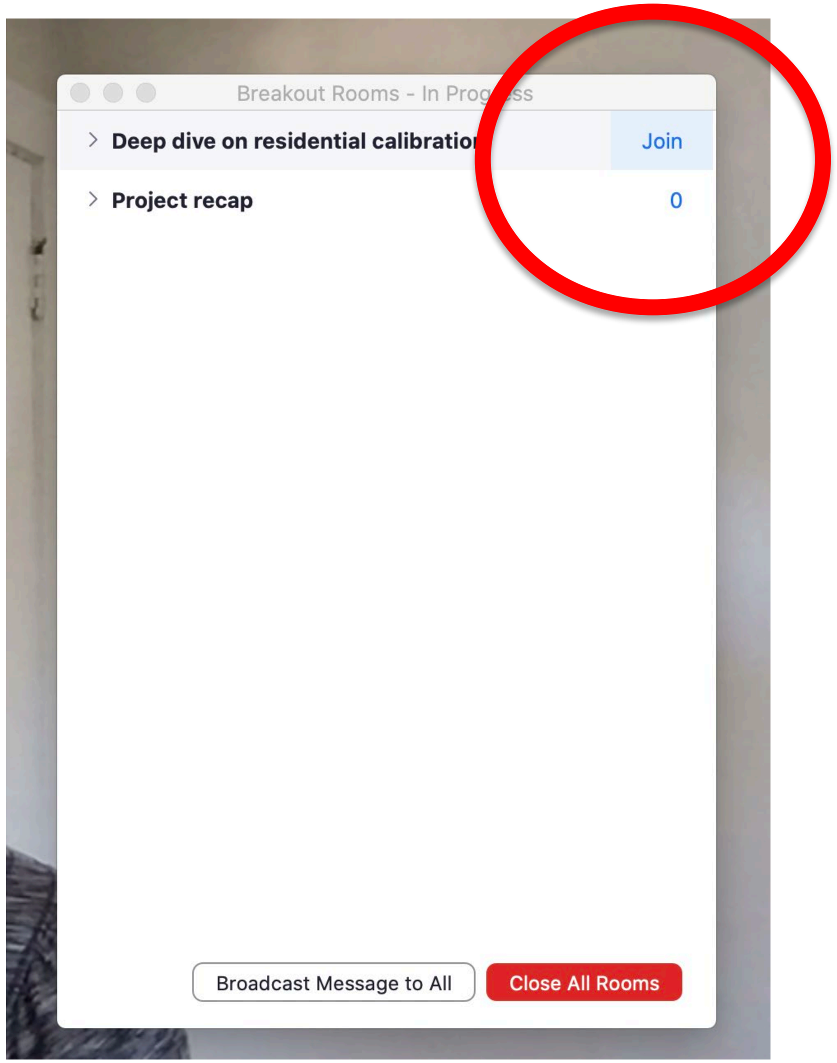


Room 1: *A method for developing general load profiles for industry*. There are no publicly-available data sources that adequately capture the variability of energy load profiles across industries. In this breakout, NREL researcher Colin McMillan will describe a method for generating general load profiles using public data on weekly, seasonal, and other operational characteristics of industry.

Room 2: *Cambium: a public dataset of hourly marginal carbon emissions and avoided cost metrics for the electric sector through 2050*. During this breakout, NREL researcher Pieter Gagnon will introduce Cambium, a newly released data product from NREL that contains highly detailed projections of the electric grid through 2050, including cost, emission, and operational metrics that are specifically designed to be useful for supporting demand-side decision-making and research.

Breakout rooms will be recorded.

Breakout group #3: Selecting your breakout room



Room 1: *Building electrification load modeling panel.* Join a panel of researchers from NREL to learn about past and ongoing laboratory and field studies being used to characterize and model the performance of building electrification technologies such as variable speed heat pumps and heat pump water heaters.

Room 2: *Distributed PV Adoption Modeling with dGen*. During this breakout NREL researcher Paritosh Das will discuss NREL's dGen model, an open source tool used to forecast technical and economic potential and adoption of DERs. He will provide an overview of how to use dGen and the role DERs play in an evolving power system.

Breakout rooms will be recorded.

Join us again tomorrow for Day 2 starting at 10 am MT!

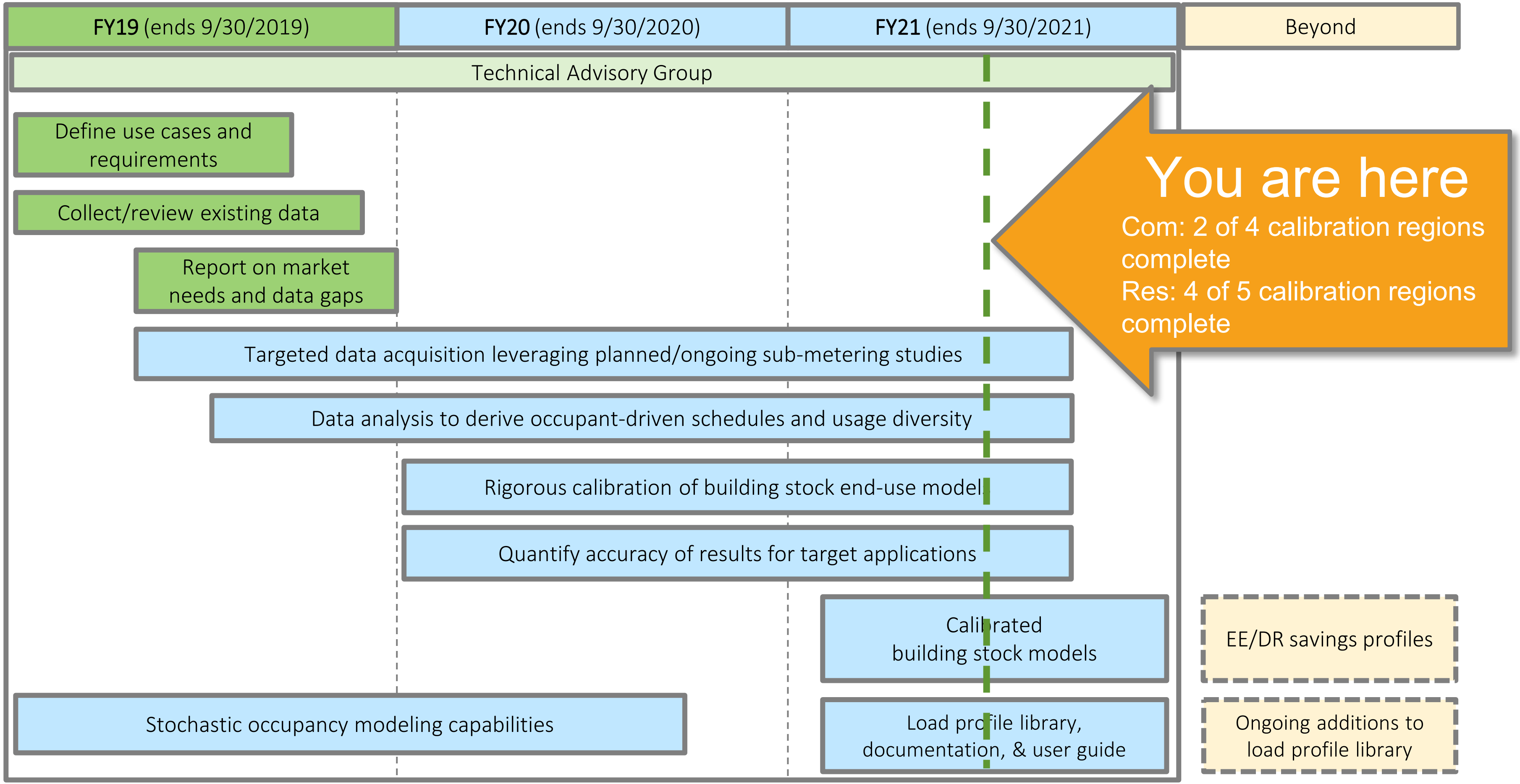
NREL
Transforming ENERGY

End-Use Load Profiles for the U.S. Building Stock: Calibration Progress Summary

Eric Wilson, Andrew Parker

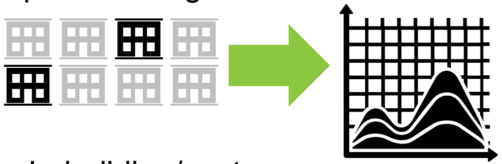
April 21, 2021

Project Timeline



Solution: A Hybrid Approach (2)

End-use data for
sampled buildings

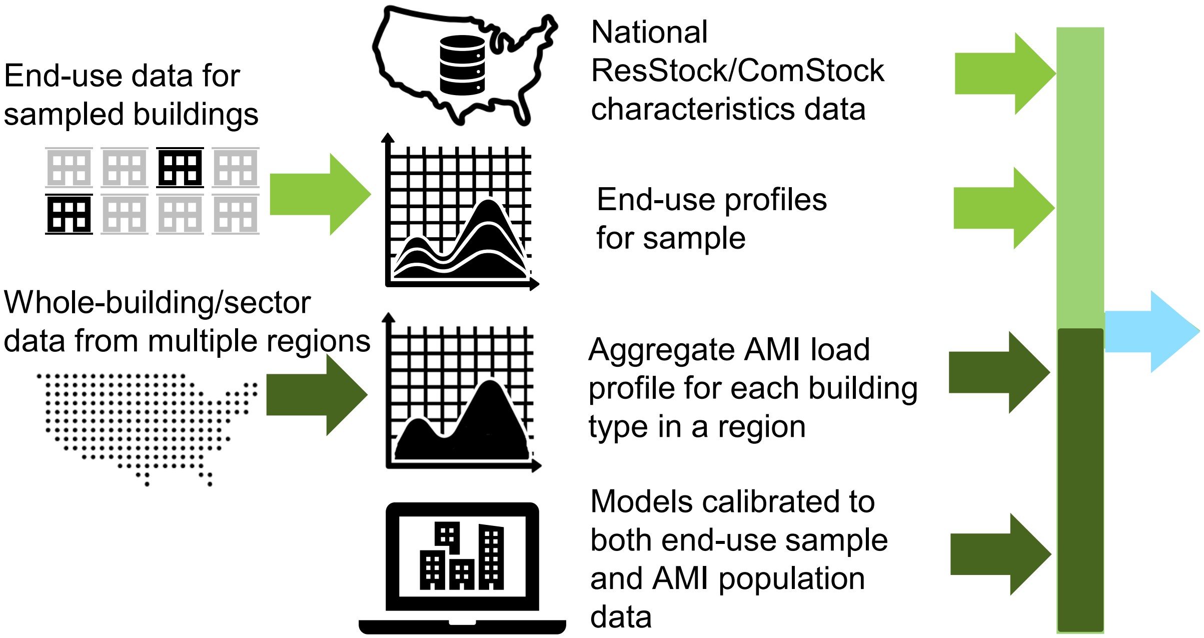


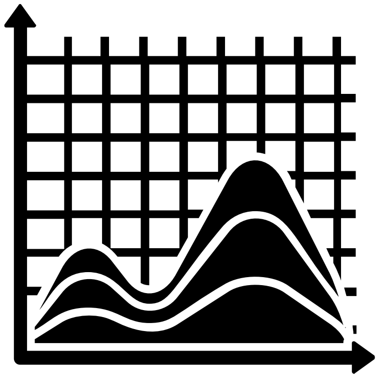
End-use profiles
for sample

Whole-building/sector
data from multiple regions

Aggregate AMI load
profile for each building
type in a region

Solution: A Hybrid Approach (2)





- Validated at *both* the end use level and population level

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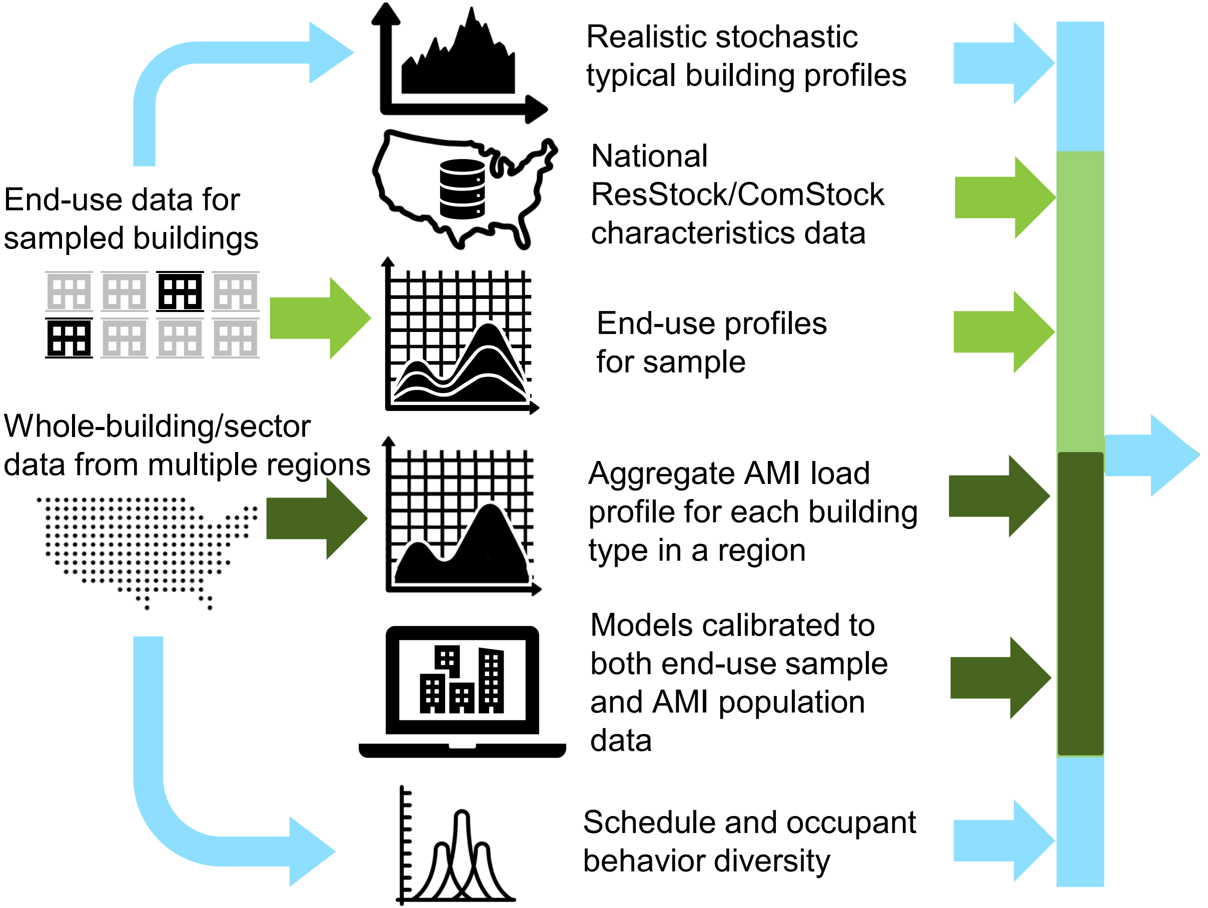

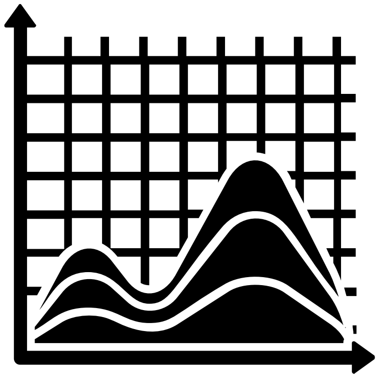

- Validated at *both* the end use level and population level
- Validated diversity and individual typical building profiles as well (enables more use cases)

Guiding Principles

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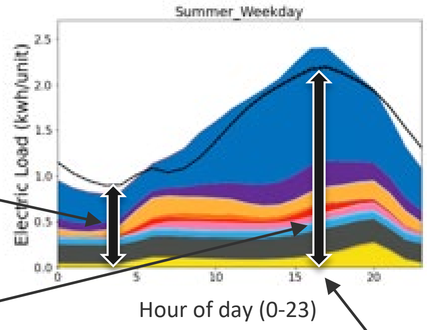
- Make changes that are supported by data and domain experience, not simply to get a better fit
- Report out accuracy and uncertainty so users can decide if they want to use

Quantities of Interest (QOI)
by building type and region

- Annual energy use (MWh)
- Average daily minimum magnitude (MW)
  - Summer, All days
  - Winter, All days
  - Shoulder, All days
- Average daily maximum magnitude (MW)
  - Summer, All days
  - Summer, Top 10 days
  - Winter, All days
  - Winter, Top 10 days
  - Shoulder, All days



- Average daily maximum load timing (hour of day)
  - Summer, All days
  - Summer, Top 10 days
  - Winter, All days
  - Winter, Top 10 days
  - Shoulder, All days

Residential Calibration Dimensions

AMI data from **Vermont; Cherryland, MI**

AMI data from Electric Power Board of **Chattanooga, TN Horry Electric (SC),** and City of **Tallahassee, FL**

AMI data (aggregated by building type) from **Seattle City Light, WA**

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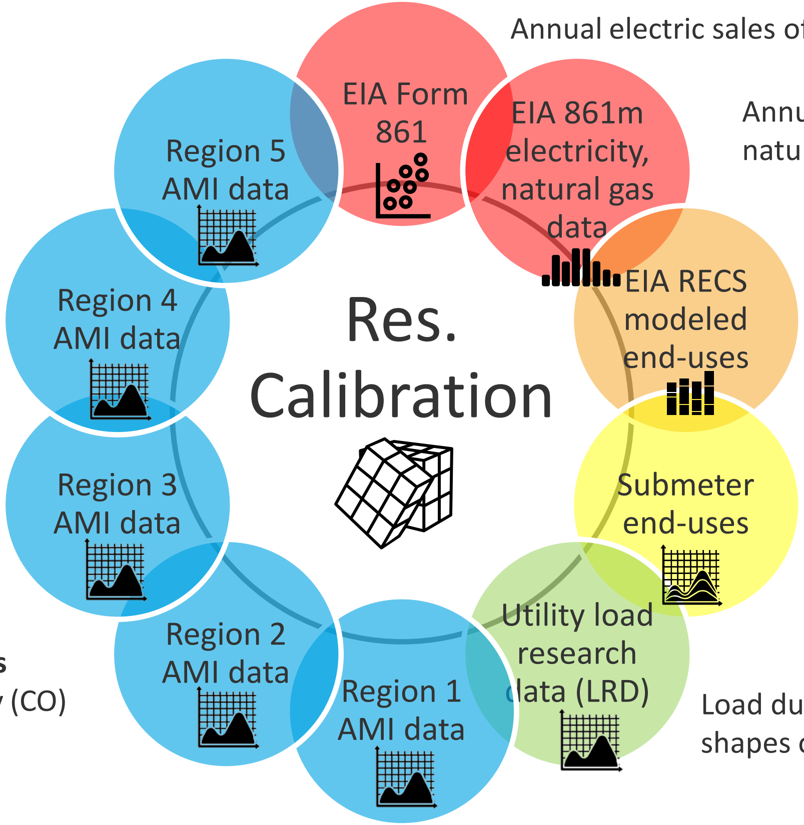


Annual electric sales of all utilities in U.S.

Annual and monthly electricity and natural gas consumption by state, sector

Annual end-use loads of occupied dwelling units

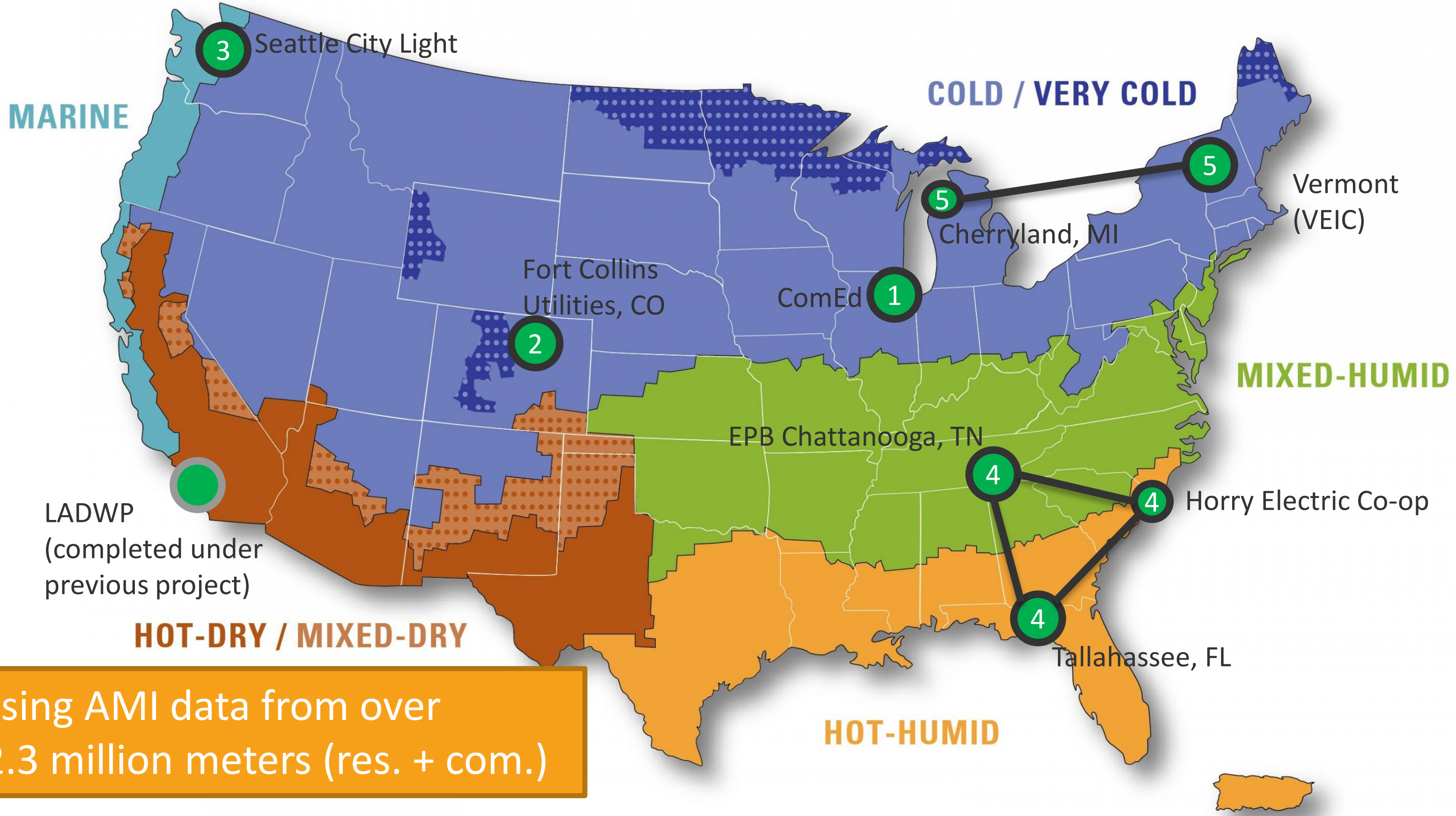
- Building type
- Climate zone
- Fuel (electricity, natural gas, propane, fuel oil)

Sub-metered end-use load data (5 datasets)

Load duration curves and seasonal load shapes of ~16 utilities around U.S.

Advanced metering infrastructure (AMI) data from **ComEd** service territory (IL)

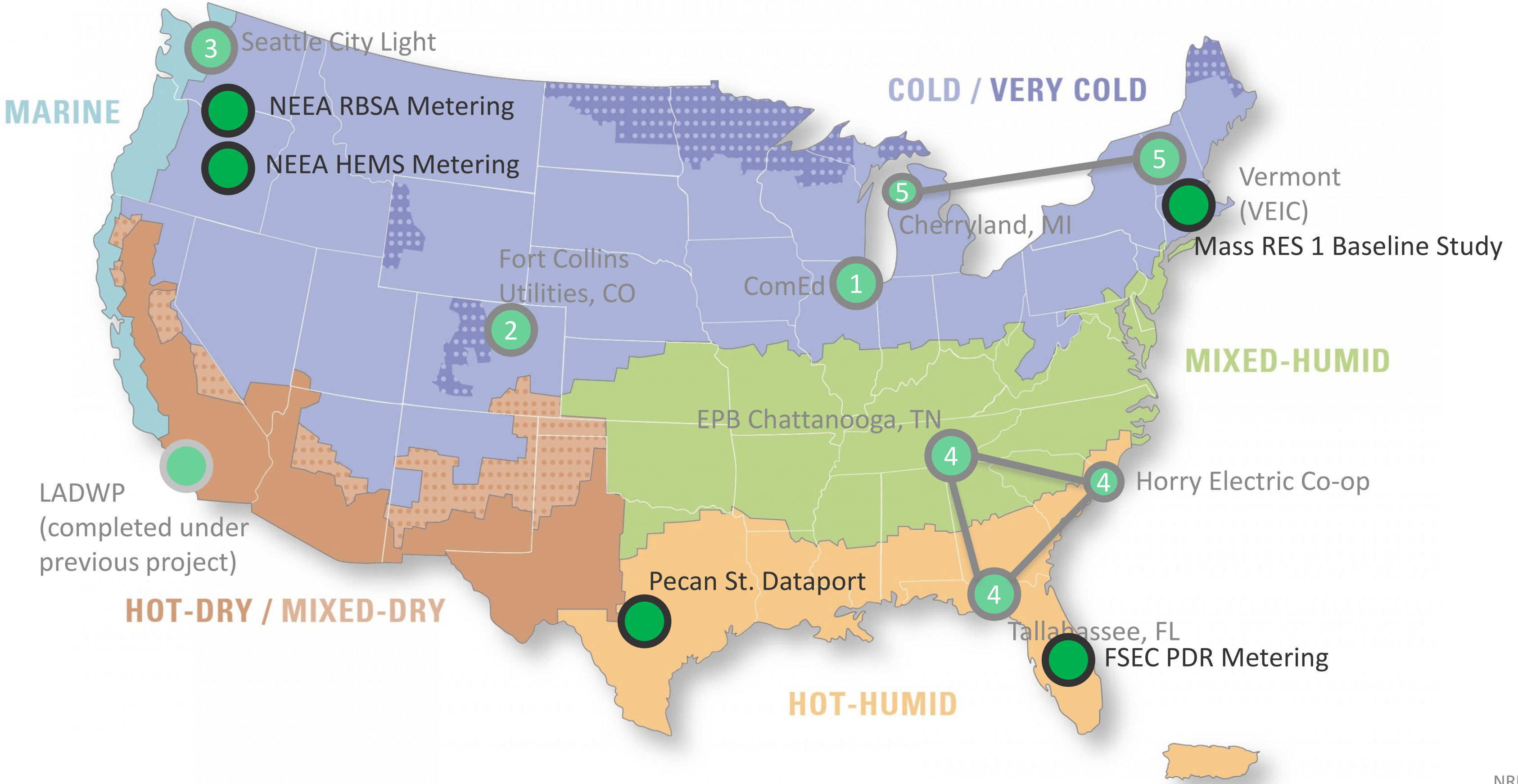
Summary of Residential AMI Calibration Regions



Using AMI data from over 2.3 million meters (res. + com.)

Background colors are DOE Building America Climate Regions

Summary of Residential Submeter Datasets



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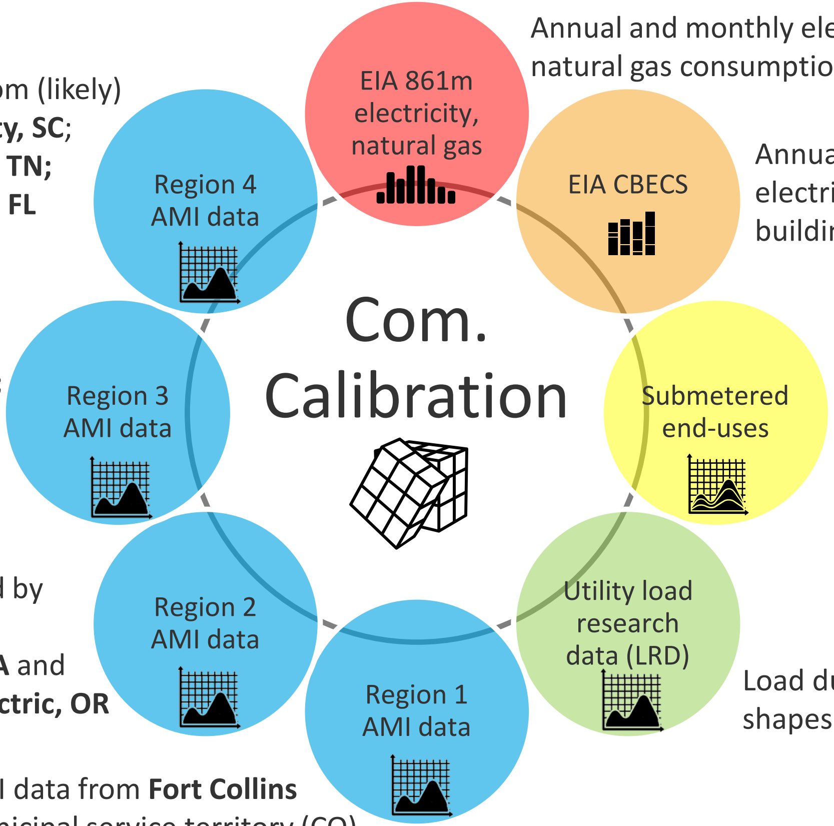
Commercial Calibration Dimensions



Annual and monthly electricity and natural gas consumption by state, sector

Annual gas and electricity EUIs by building type

Sub-metered end-use load data

Load duration curves and seasonal load shapes of ~16 utilities around U.S.

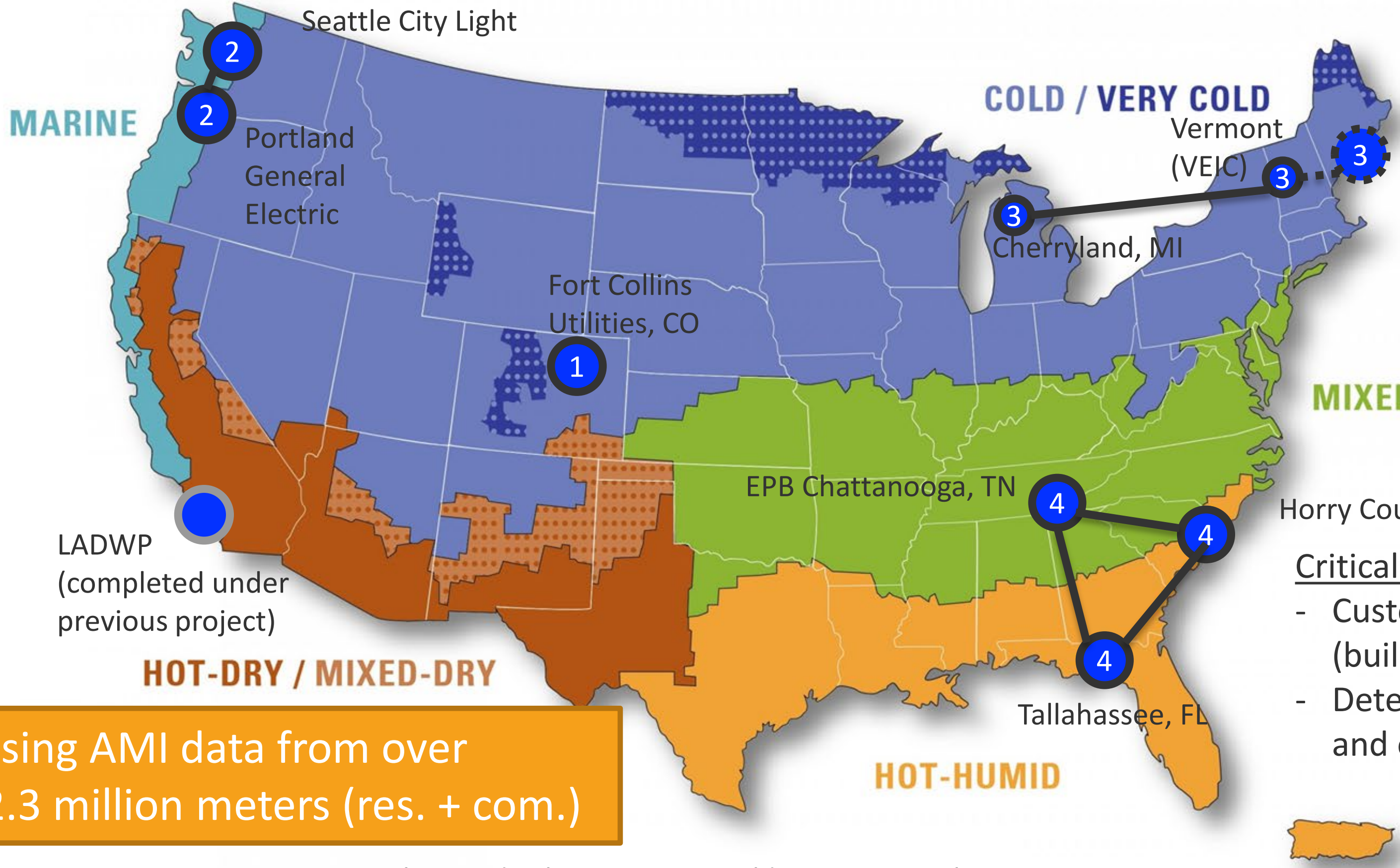
AMI data from **Fort Collins** municipal service territory (CO)

AMI data (aggregated by building type) from **Seattle City Light, WA** and **Portland General Electric, OR**

AMI data from **Vermont; Maine; Cherryland, MI**

AMI data from (likely) **Horry County, SC**; **Chatanooga TN; Tallahassee, FL**

Summary of Commercial AMI Calibration Regions



Critical for Commercial:
- Customer metadata (building type, floor area)
- Detection of misclassification and outliers

Using AMI data from over 2.3 million meters (res. + com.)

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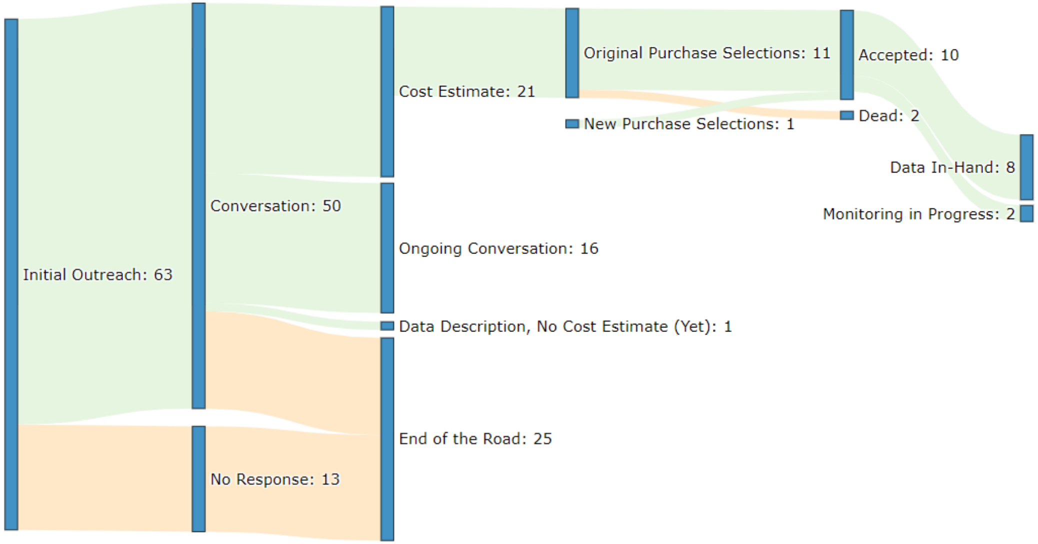
Commercial End-Use Data Procurement

- Summary
  - Major outreach effort, >700 hours
  - 10 datasets purchased



Putting Our Industry's Data to Work: A Case Study of Large-Scale Data Aggregation

Preprint

Elaina Present,[1] Chris CaraDonna,[1] Eric Wilson,[1] Natalie Frick,[2] Janghyun Kim,[1] Rajendra Adhikari,[1] Anna C. McCreery,[3] and Elizabeth Titus[4]

1 National Renewable Energy Laboratory
2 Lawrence Berkeley National Laboratory
3 Elevate Energy
4 Northeast Energy Efficiency Partnerships

Presented at the 2020 ACEEE Summer Study on Energy Efficiency in Buildings
August 17-21, 2020

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Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-5500-77102
September 2020

https://www.nrel.gov/docs/fy20osti/77102.pdf

So how's it going?

Residential Calibration

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- Region 5 of 5 to finish in July 2021

Commercial Calibration

- Getting an accurate ground truth to use for calibration is challenging and critical
  - Submeter data not readily available, we had to get creative and procure from a range of companies
  - AMI data is only useful if you know building type and size, so we had to develop ways to match metadata that avoid privacy concerns
  - Developed process for removing outliers (e.g., misclassified building types, missing meters)
  - AMI sample size is small for some utility/building type combos – can't rely on AMI alone
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- Region 3 of 4 to finish in May 2021, Region 4 of 4 to finish in August 2021

Looking Ahead

- Quantitative accuracy assessments will be presented:
  - Residential Calibration Update (up next)
  - Commercial Calibration Update (tomorrow)
- Final calibration updates presented to TAG in August 2021
- Final assessments will be published in the *Methodology and Results* report (draft in Sept.)

Residential Region 4 Calibration

Anthony D. Fontanini, Ph.D.
Eric Wilson
April 21, 2021

Calibration Strategy

Residential Calibration Dimensions

Adjusted for PV generation and billing periods

Annual electric sales of all utilities in U.S.

Annual and monthly electricity and natural gas consumption by state, sector

Annual end-use loads of occupied dwelling units
- Building type
- Climate zone
- Fuel (electricity, natural gas, propane, fuel oil)

Sub-metered end-use load data (5 datasets)

Updated from 2012 to 2018

Load duration curves and seasonal load shapes of ~16 utilities around U.S.

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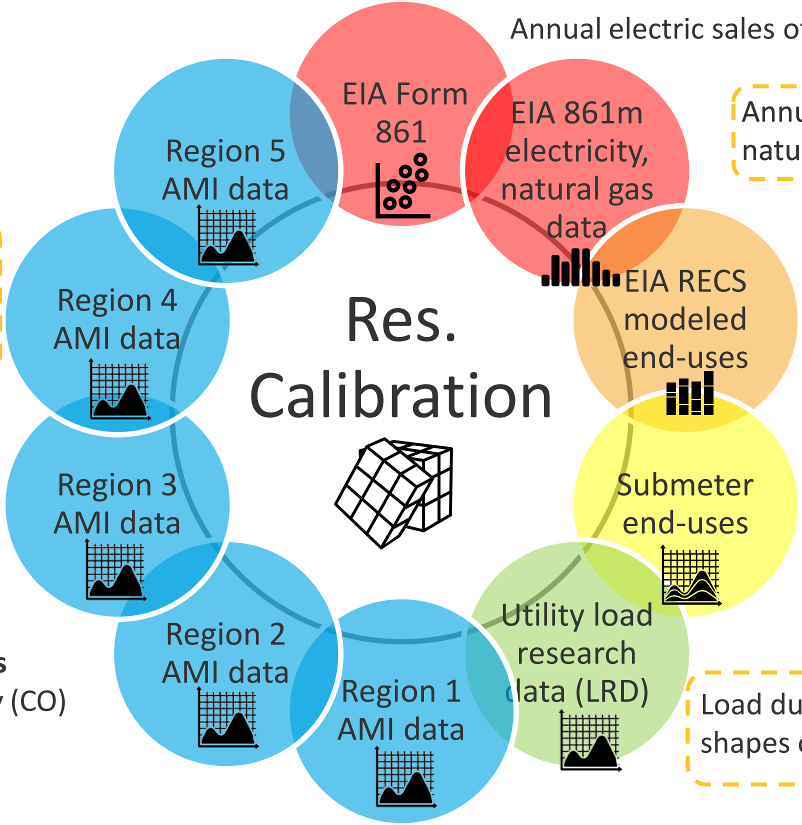

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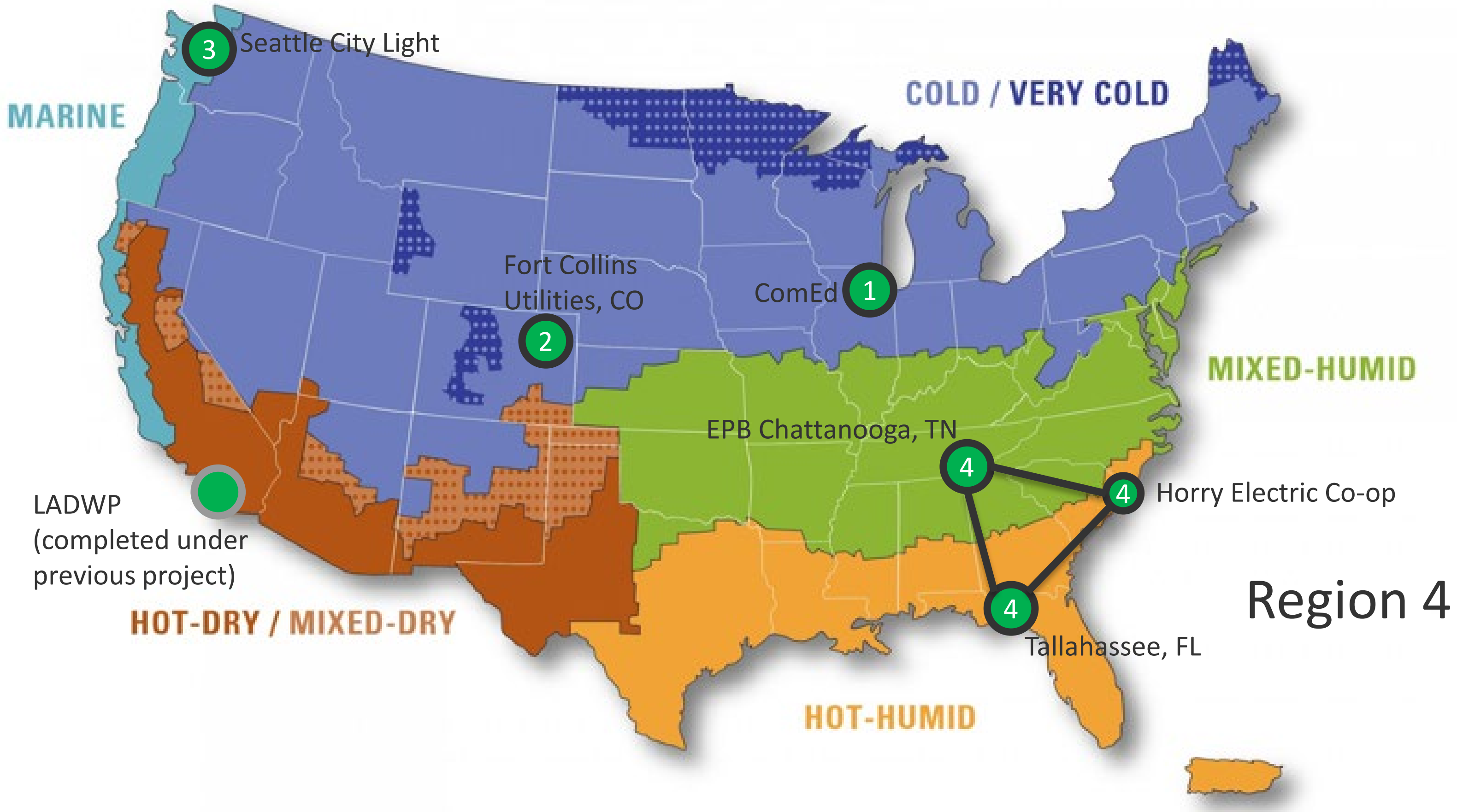

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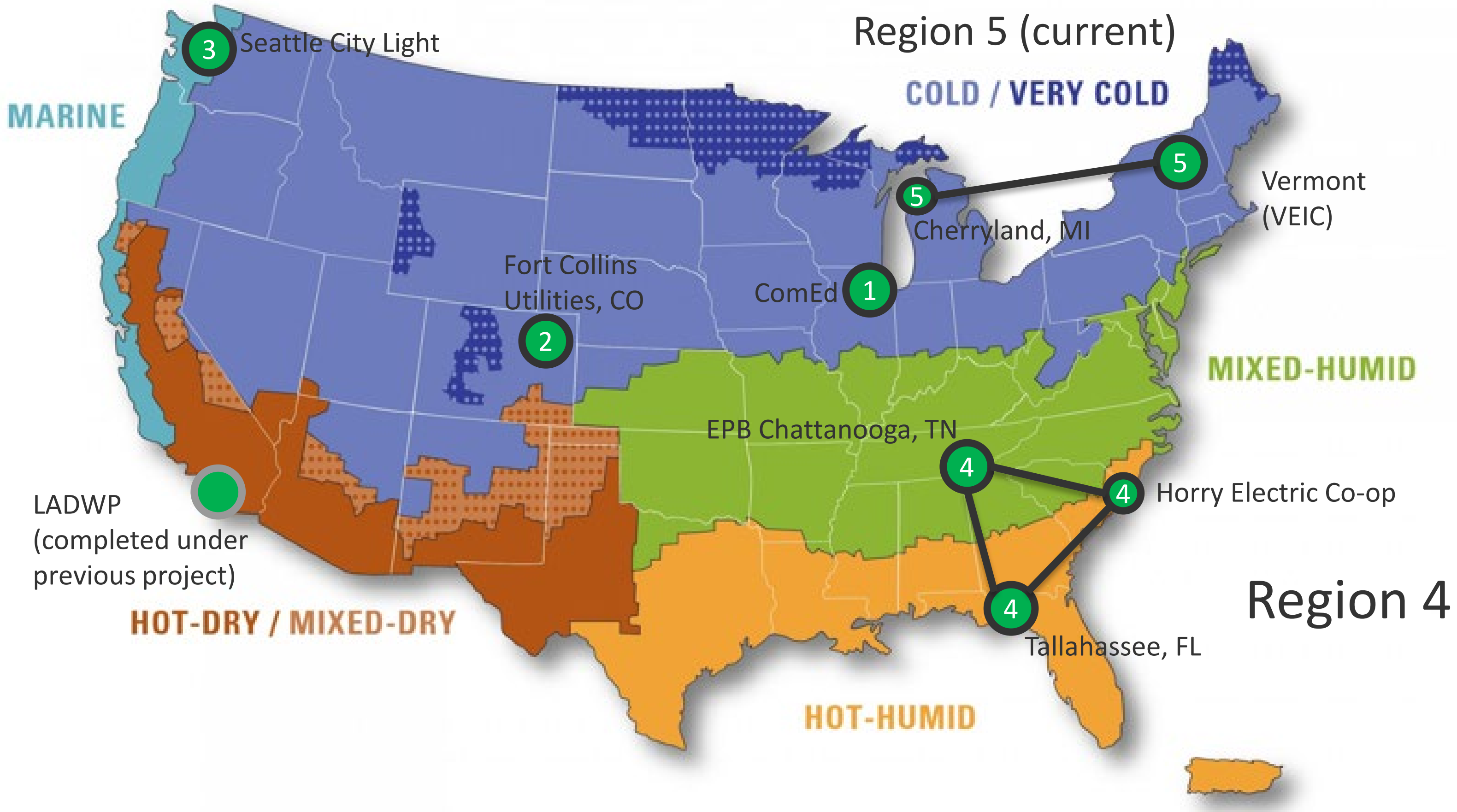
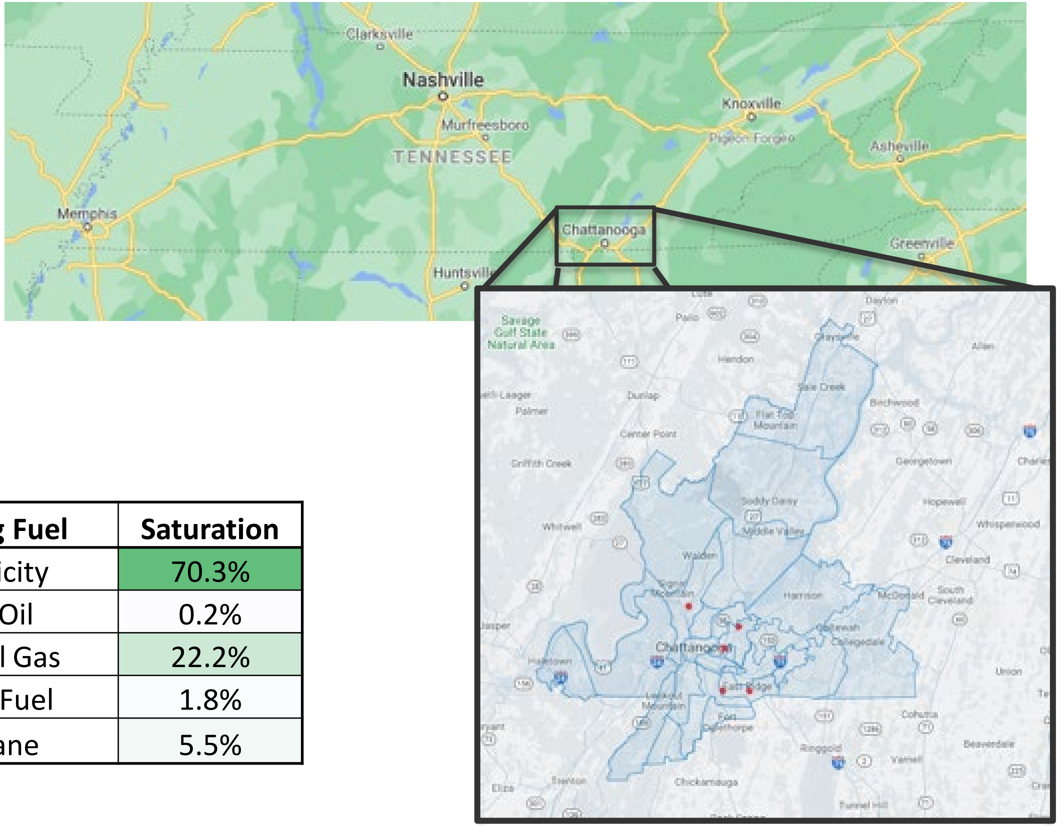


Region 4 – Electric Power Board (EPB) of Chattanooga

- Serves ~158,000 customers in TN and GA
- Municipal utility
- Used AMI data from 2019
- Compared to previous regions:
  - Higher % electric heating

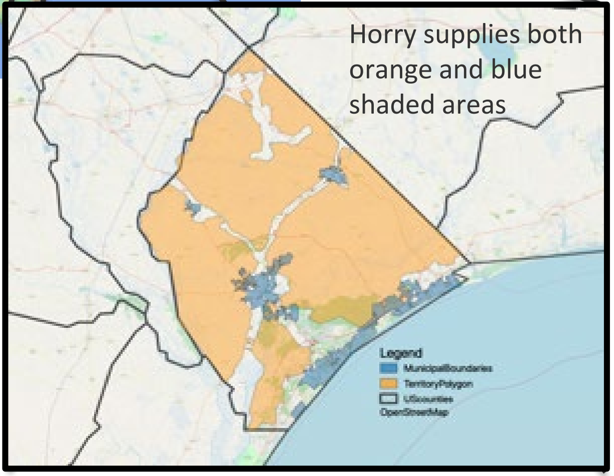


Building Type RECS	Saturation
Mobile Home	9.8%
Multi-Family with 2 - 4 Units	7.3%
Multi-Family with 5+ Units	10.0%
Single-Family Attached	2.3%
Single-Family Detached	70.7%

Heating Fuel	Saturation
Electricity	70.3%
Fuel Oil	0.2%
Natural Gas	22.2%
Other Fuel	1.8%
Propane	5.5%

Region 4 – Horry Electric Cooperative

- Serves ~68,000 customers in SC
- Serves most of Horry County, including several municipalities via franchise agreements
- Used AMI data from 2018
- Compared to previous regions:
  - Higher % electric heating
  - Higher % of vacant/vacation units
  - Large fraction of population is near the coast



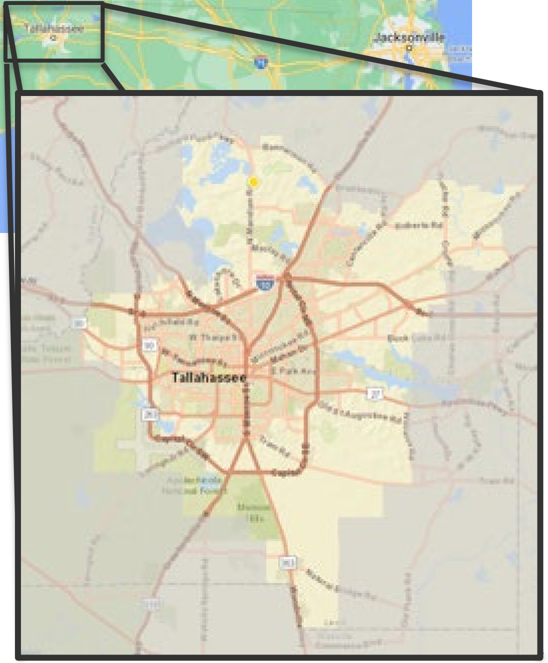
Building Type RECS	Saturation
Mobile Home	15.0%
Multi-Family with 2 - 4 Units	5.0%
Multi-Family with 5+ Units	18.0%
Single-Family Attached	4.5%
Single-Family Detached	57.4%

Building Type RECS	Percent Vacant
Mobile Home	27.7%
Multi-Family with 2 - 4 Units	37.5%
Multi-Family with 5+ Units	66.4%
Single-Family Attached	38.9%
Single-Family Detached	20.6%

Heating Fuel	Electricity	Fuel Oil	Natural Gas	None	Propane
Saturation	94.5%	0.1%	3.0%	0.1%	2.3%

Region 4 – City of Tallahassee

- Serves ~102,000 customers in FL
- Municipal utility
- Used AMI data from 2019
- Compared to previous regions:
  - Higher % electric heating



Building Type RECS	Saturation
Mobile Home	7.3%
Multi-Family with 2 - 4 Units	9.8%
Multi-Family with 5+ Units	22.6%
Single-Family Attached	7.5%
Single-Family Detached	53.0%

Heating Fuel	Heating Fuel
Electricity	88.5%
Fuel Oil	0.2%
Natural Gas	8.2%
Other Fuel	0.2%
Propane	2.9%

Where did we end up?

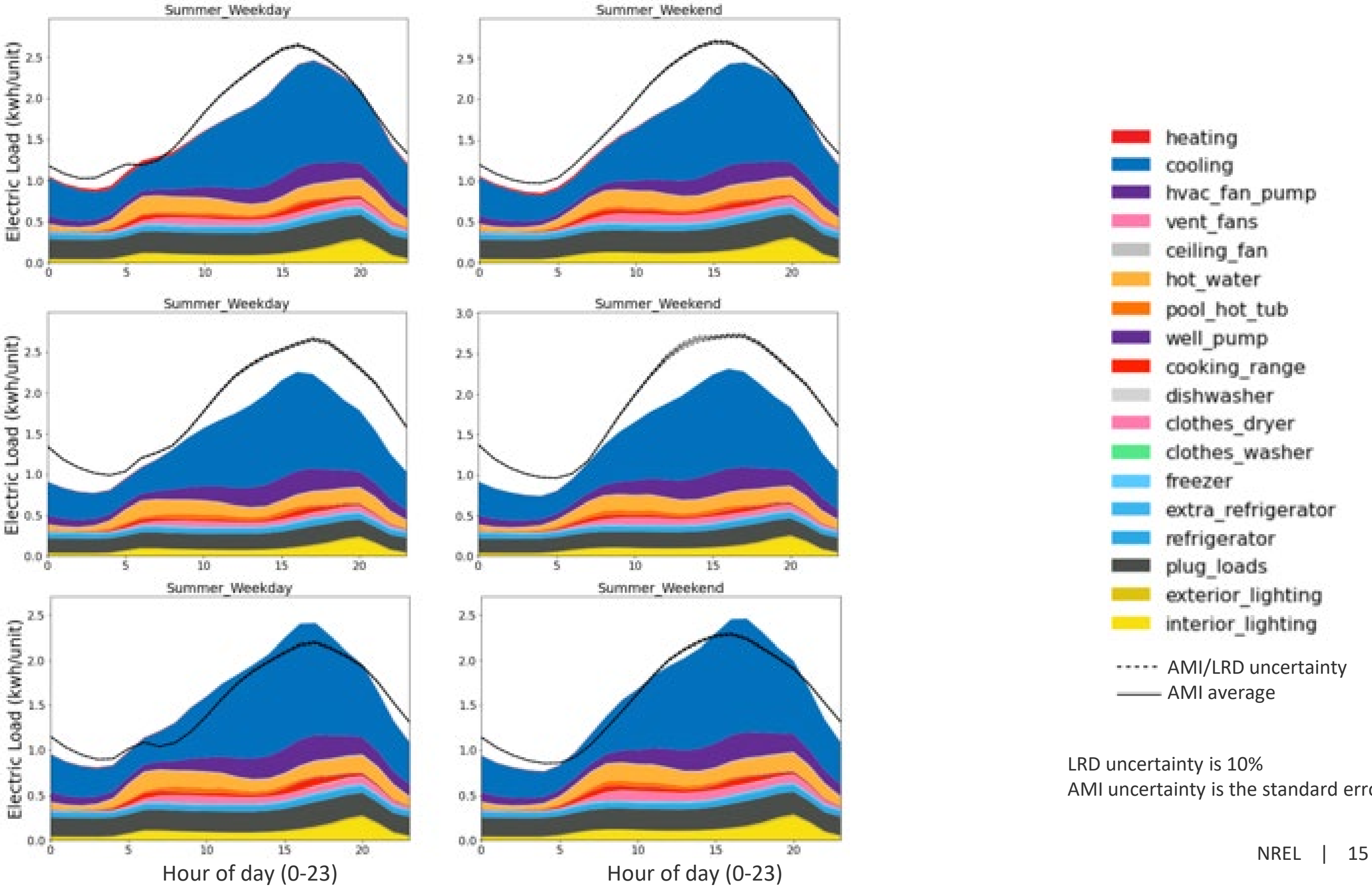
Calibration improvements and load shape status

Seasonal end-use loads by day type

EPB, Chattanooga, TN service territory

Horry Electric service territory

City of Tallahassee service territory



LRD uncertainty is 10%
AMI uncertainty is the standard error.

res_national_48_2018

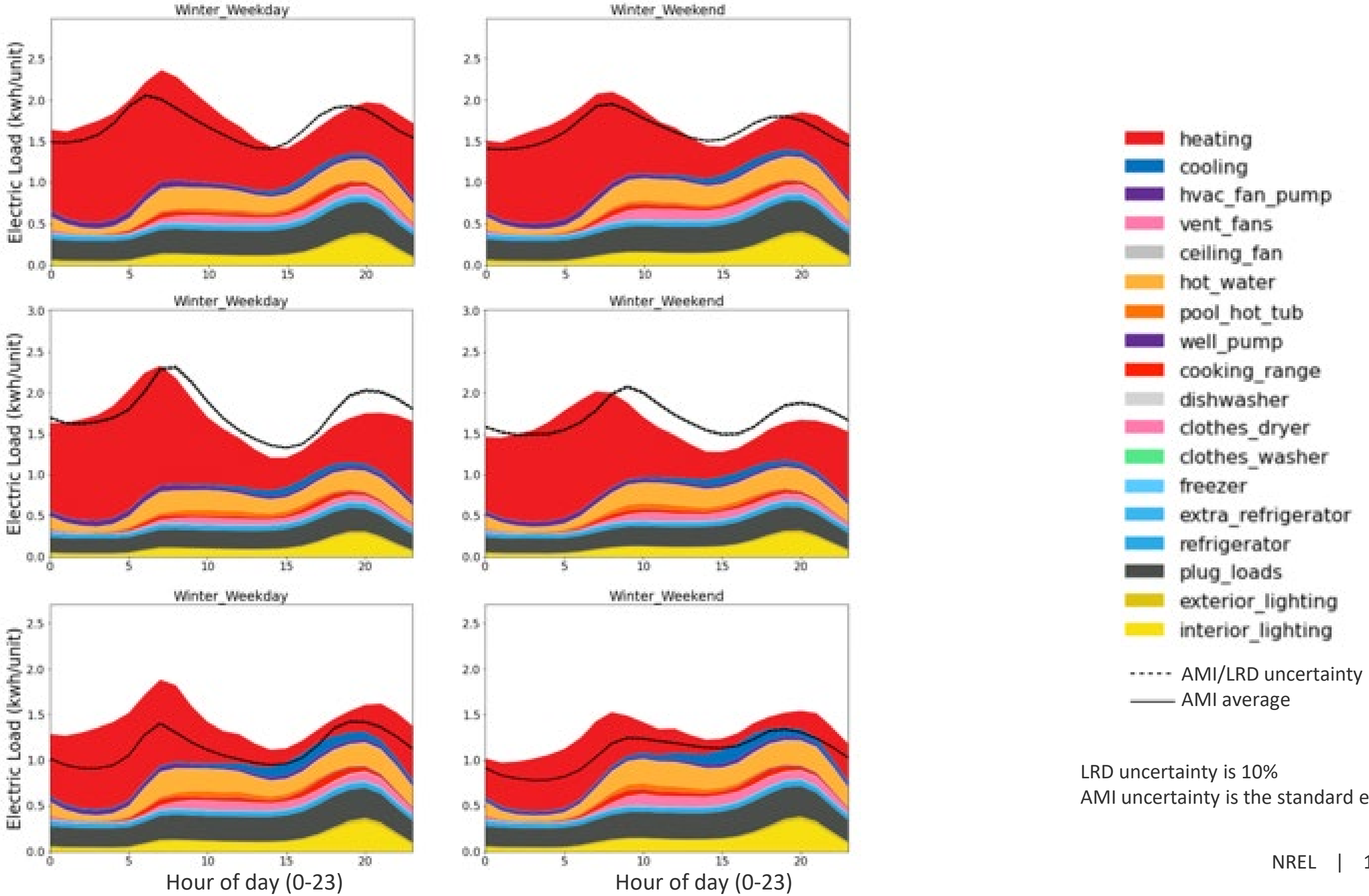
res_epb_scl_tal_48_2019

Seasonal end-use loads by day type

EPB,
Chattanooga, TN
service territory

Horry Electric
service territory

City of Tallahassee
service territory



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Seasonal end-use loads by day type

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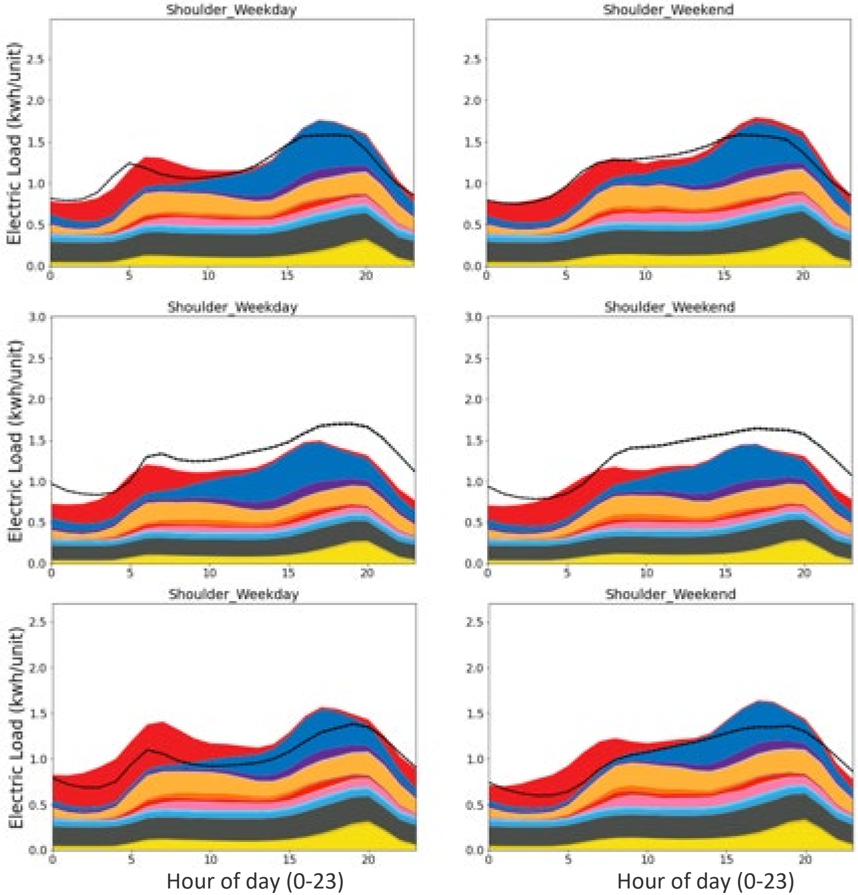
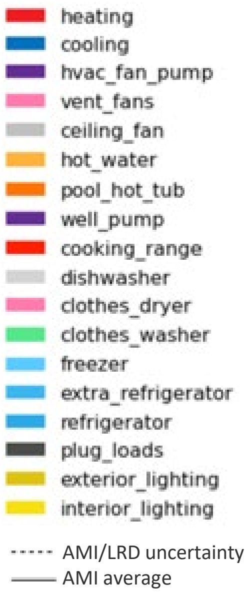




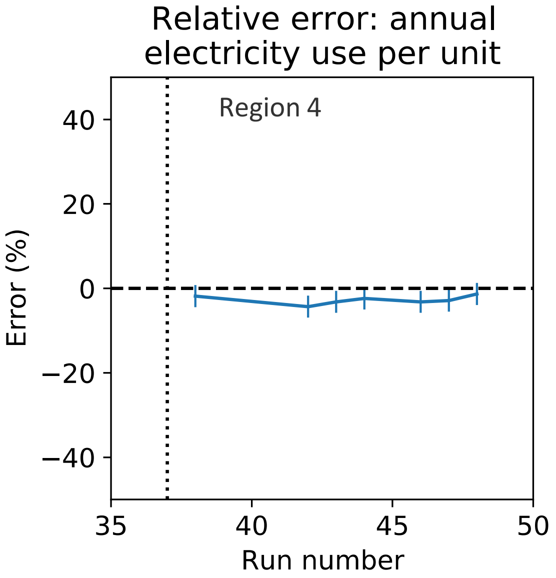
LRD uncertainty is 10%
AMI uncertainty is the standard error.

res_national_48_2018

res_epb_scl_tal_48_2019

Annual Error For Region 4 AMI datasets

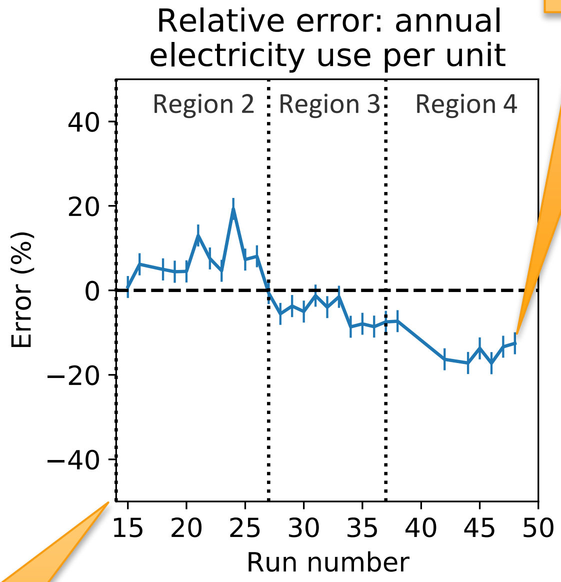
EPB, Chattanooga, TN



Only 2019 AMI data is available, so we don't have QOIs from previous 2018 runs

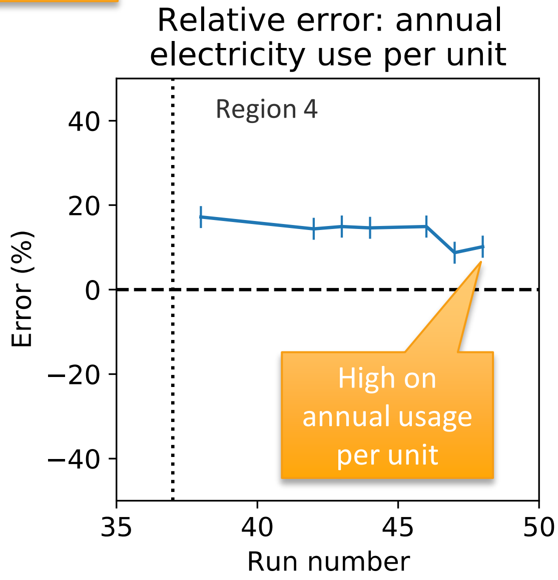
Horry Electric

Low on annual usage per unit



QOIs calculated for previous 2018 runs

City of Tallahassee



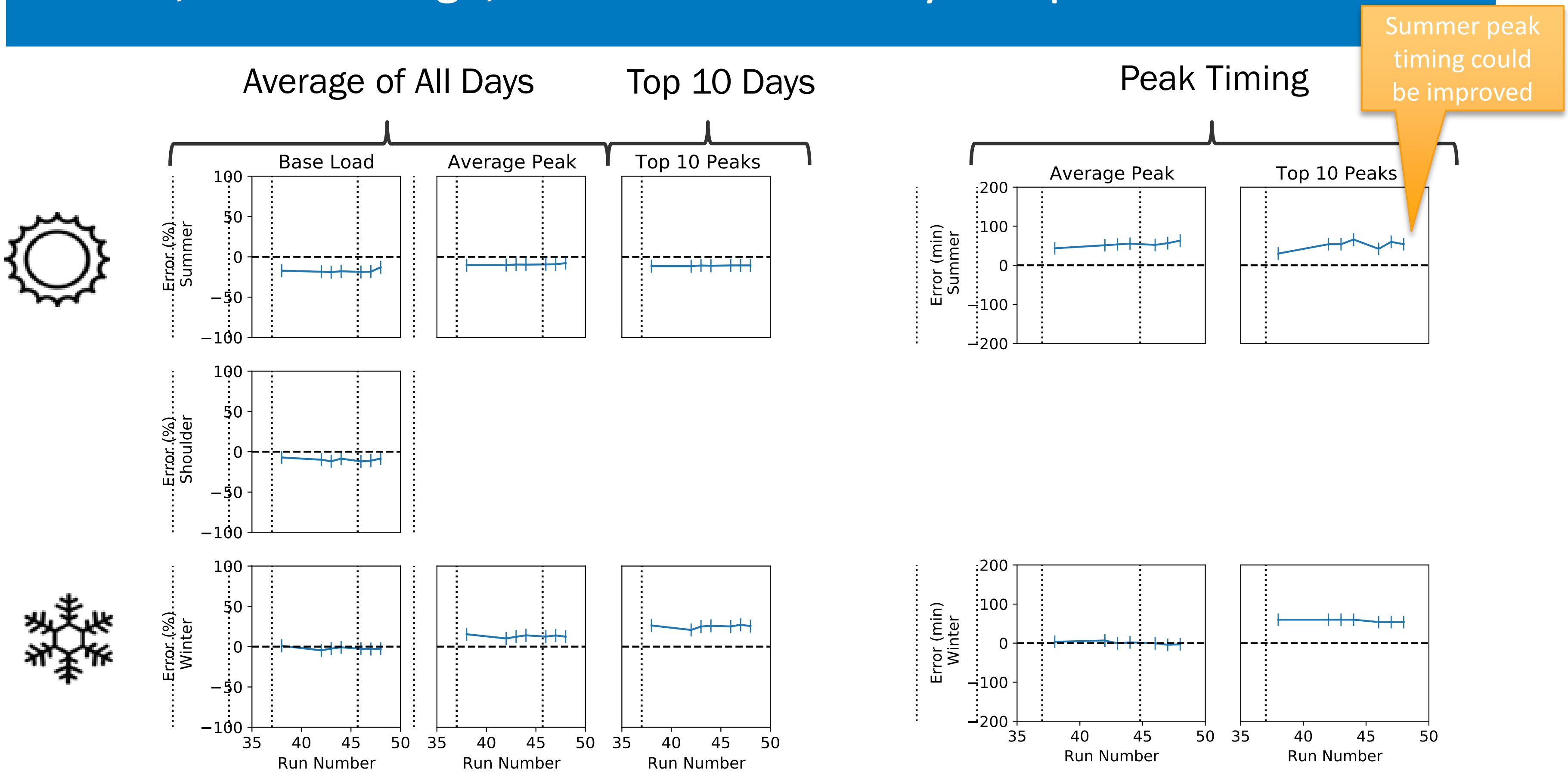
High on annual usage per unit

Only 2019 AMI data is available, so we don't have QOIs from previous 2018 runs

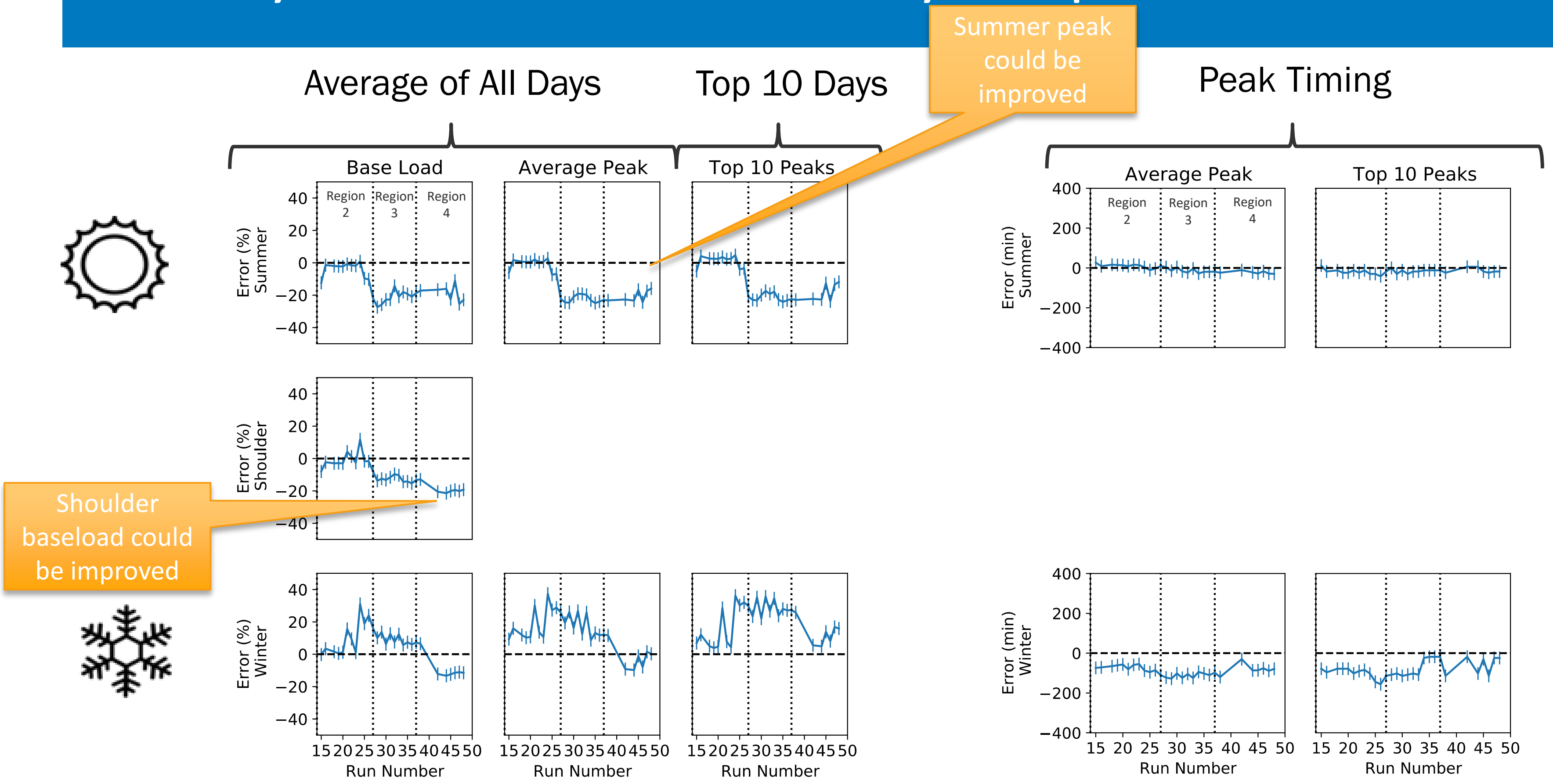
Reasons for discrepancies

- Horry: Cooling load too low
- Tallahassee: SFD load too high

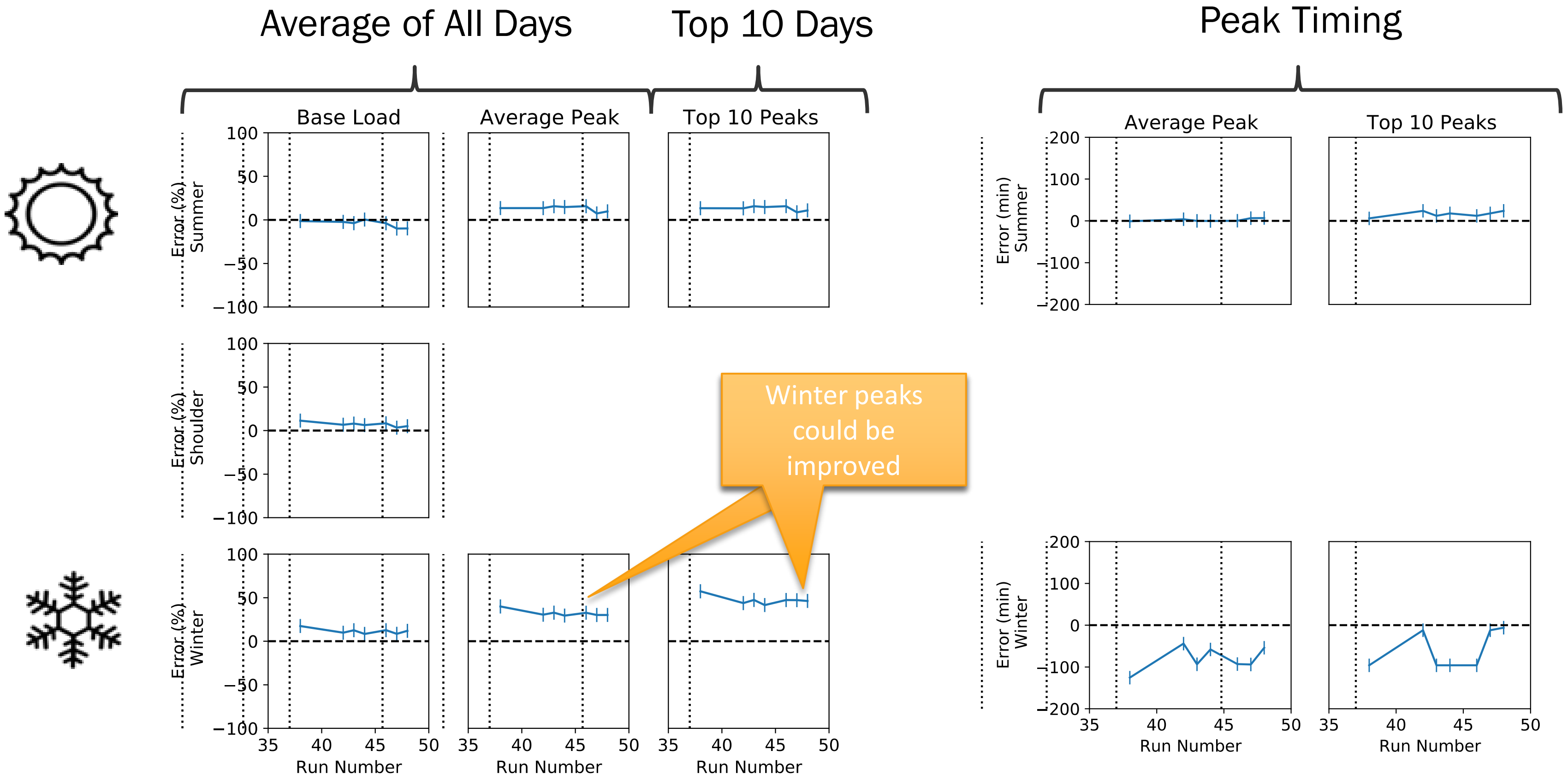
EPB, Chattanooga, TN service territory: shape error metrics



Horry Electric service territory: shape error metrics



City of Tallahassee service territory: shape error metrics

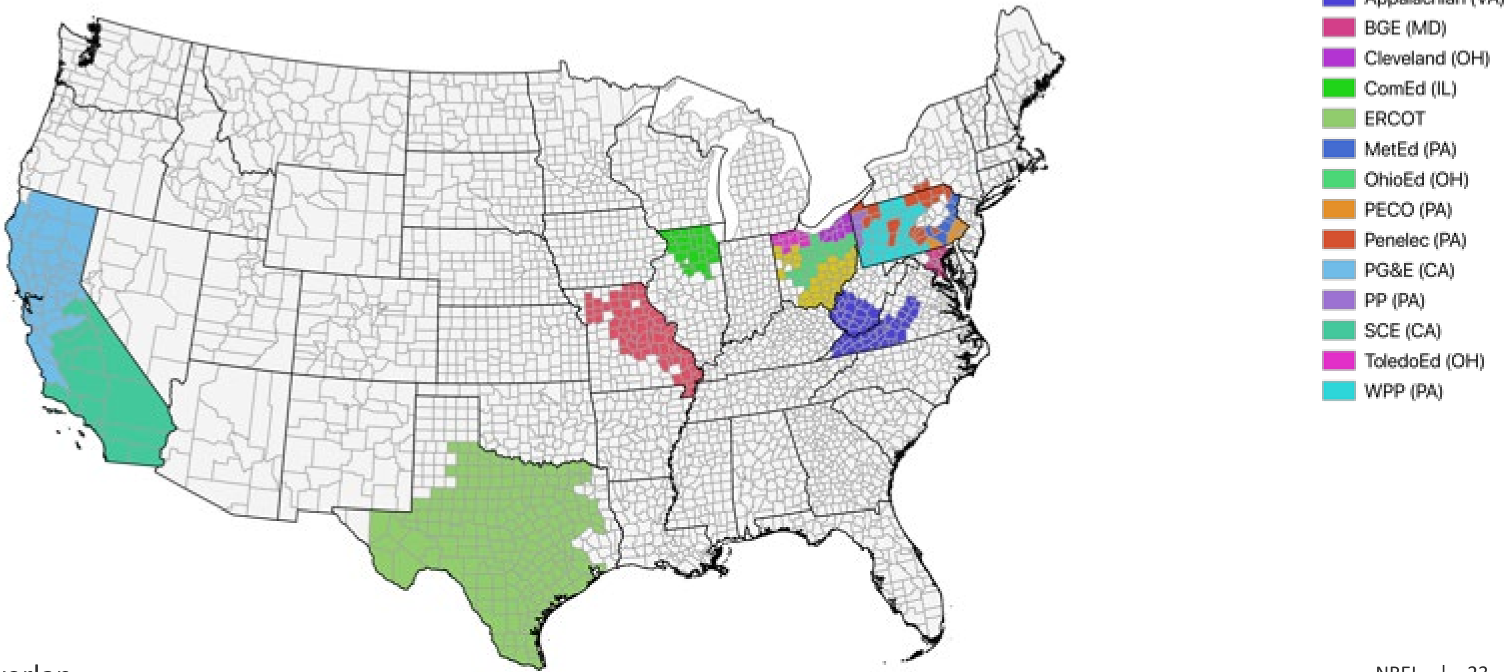


New/updated validation comparisons

2018 Load Research Data Comparisons

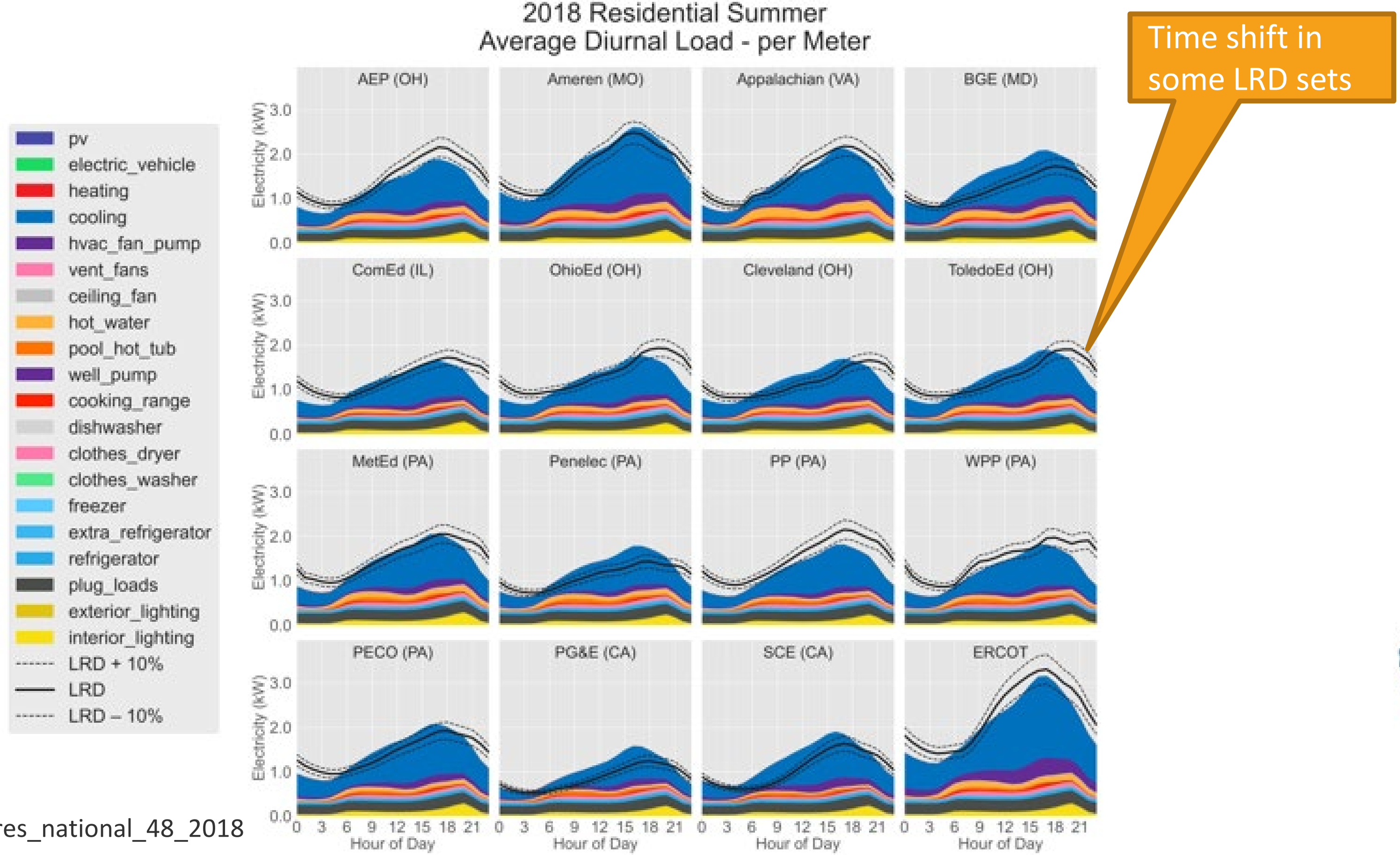
Load research data comparison updated from 2012 to 2018

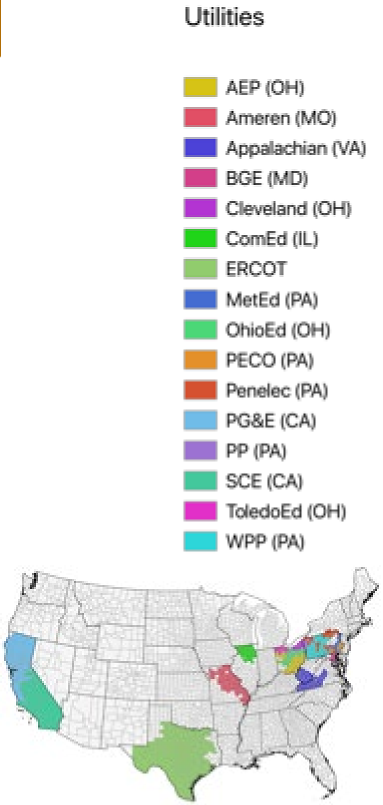
2018 utility service territory according to EIA Form 861



*Service territories may overlap

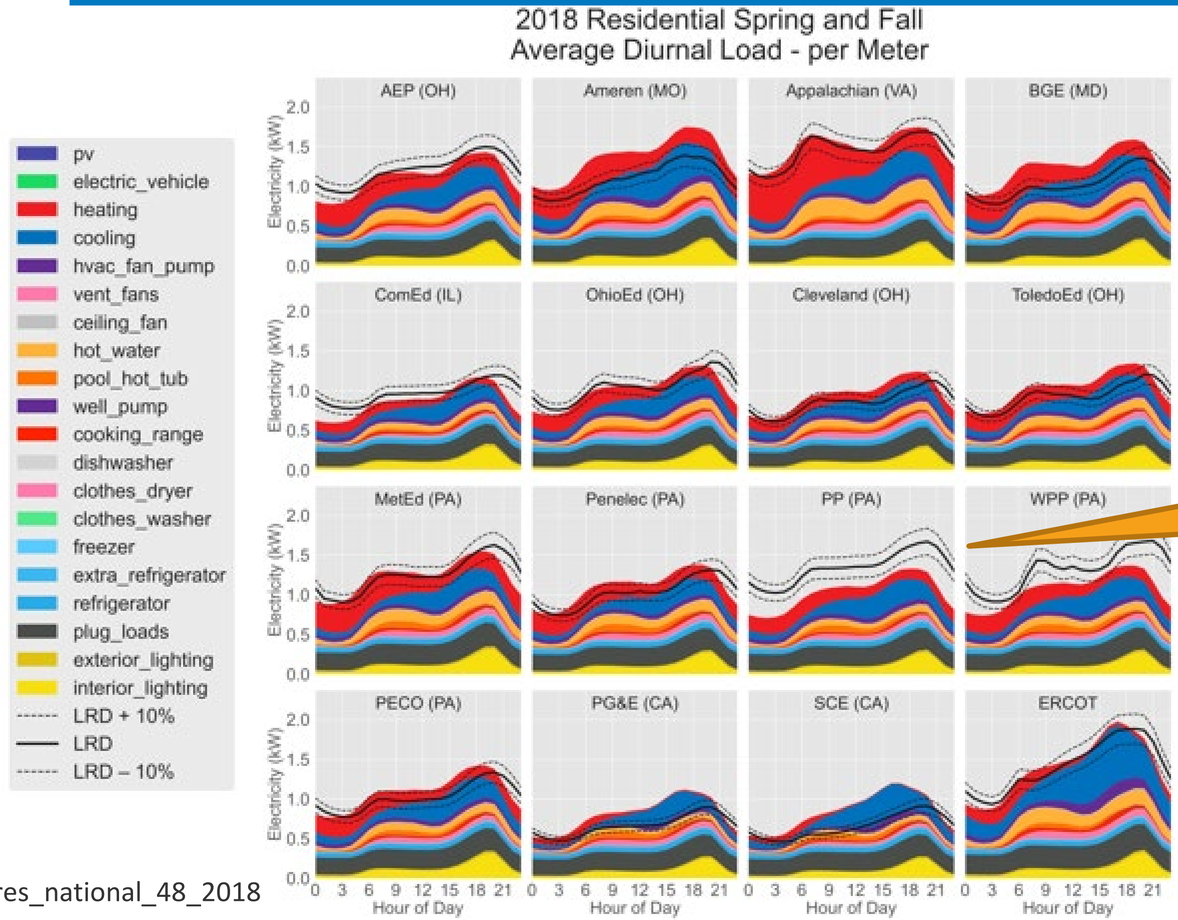
2018 Load Research Data Comparisons



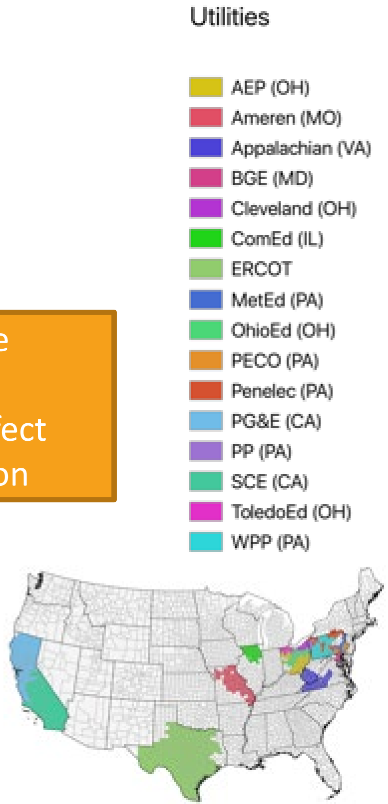


res_national_48_2018

2018 Load Research Data Comparisons

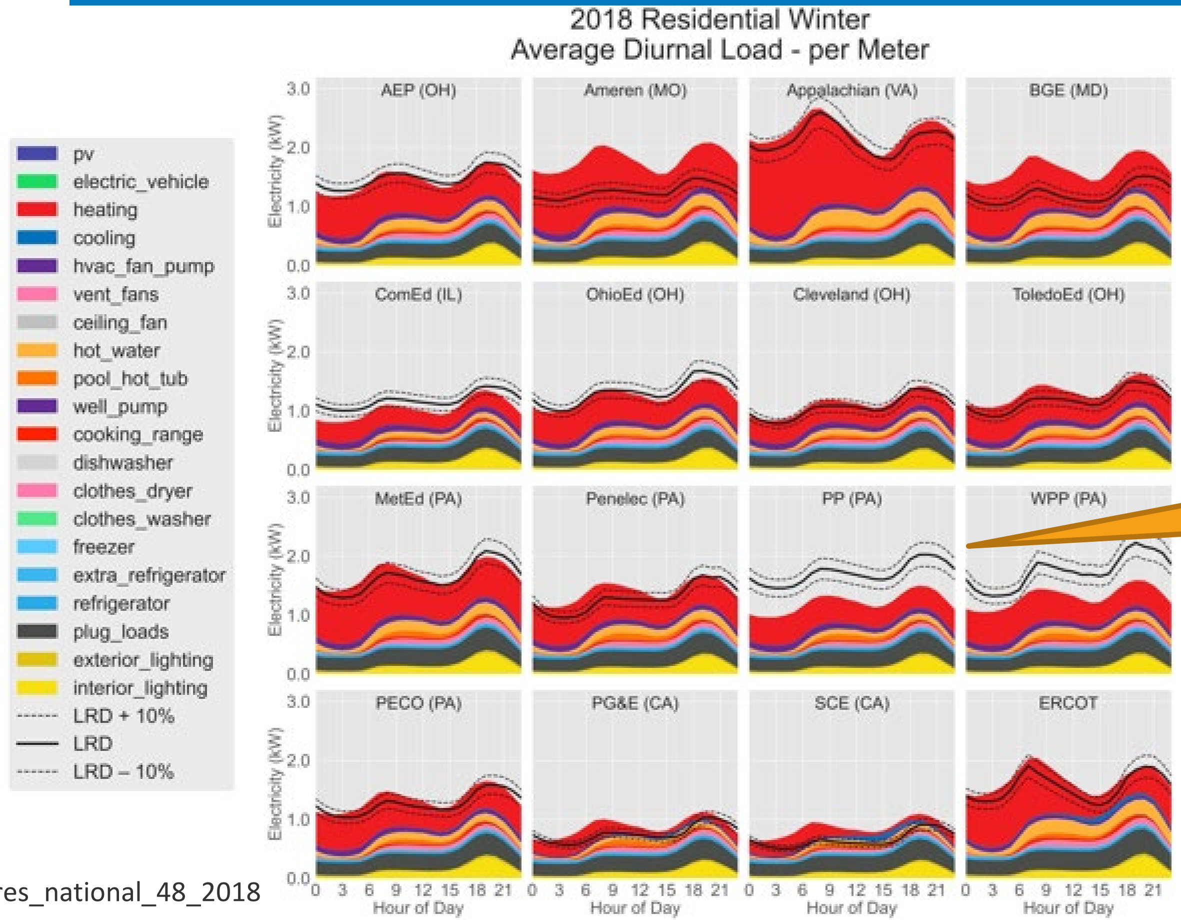


Inaccurate customer counts affect comparison

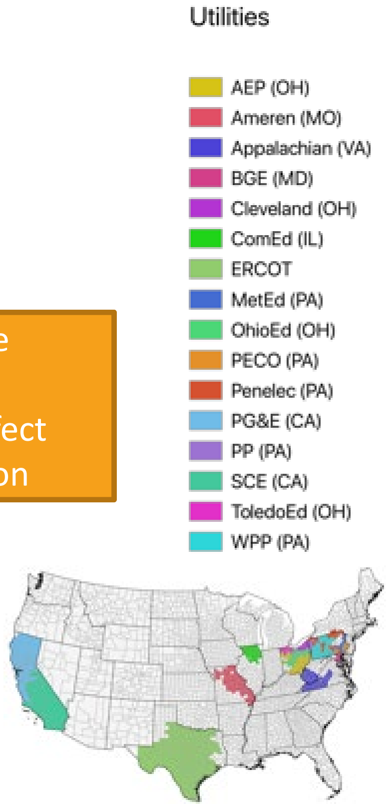


res_national_48_2018

2018 Load Research Data Comparisons



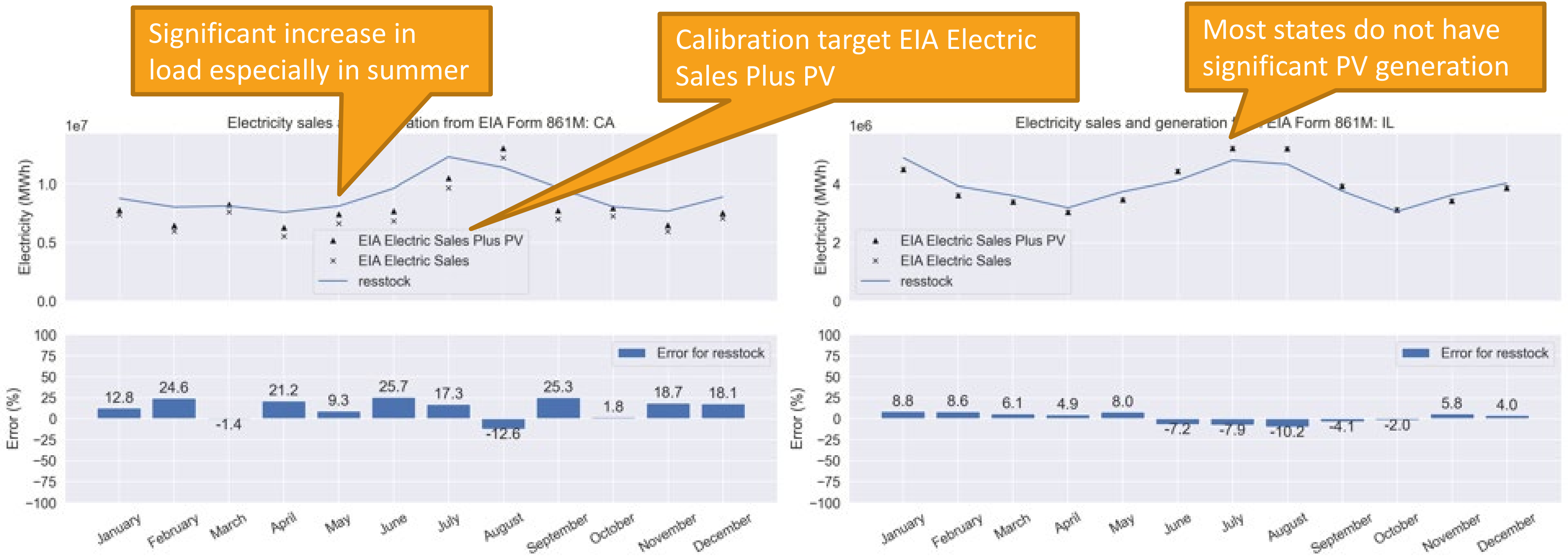
Inaccurate customer counts affect comparison



res_national_48_2018

Residential monthly EIA electricity adjusted for PV generation

- **TAG Feedback:** Behind-the-meter PV generation may be non-negligible in some states
- Introduced residential small-scale PV generation (EIA Form 861) into monthly comparisons



res_national_42_2018

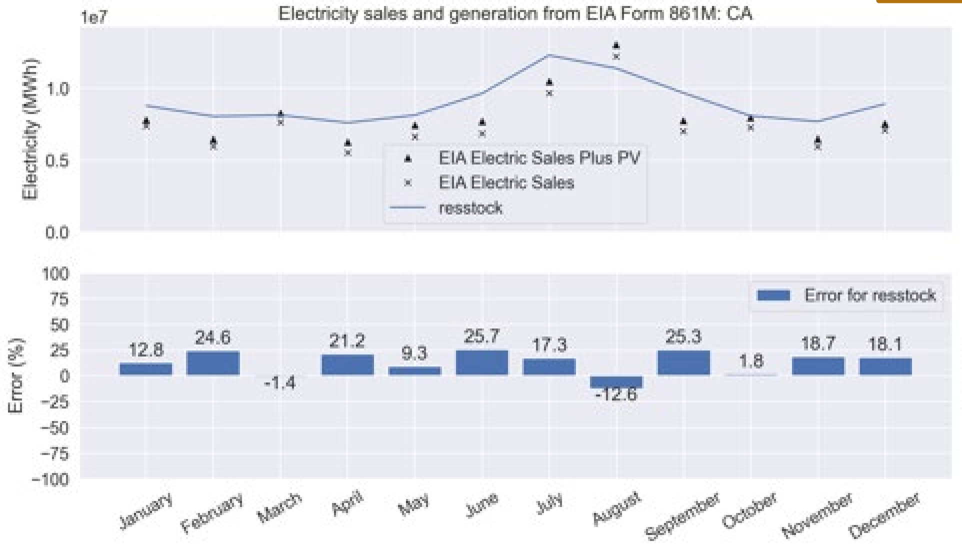
Residential monthly EIA electricity adjusted billing reporting periods

- **Not all states seem to be affected**
- TAG member used California as an example for and verified analysis by using CEC data

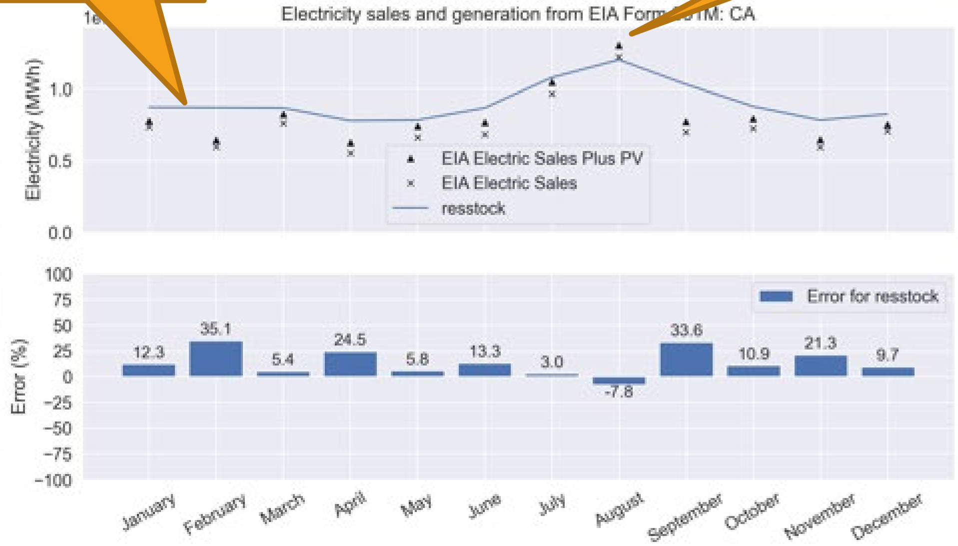
CA most likely uses billing months

Summer peak shifted

Before weighting function applied



After weighting function applied



res_national_42_2018

Residential monthly EIA electricity adjusted billing reporting periods

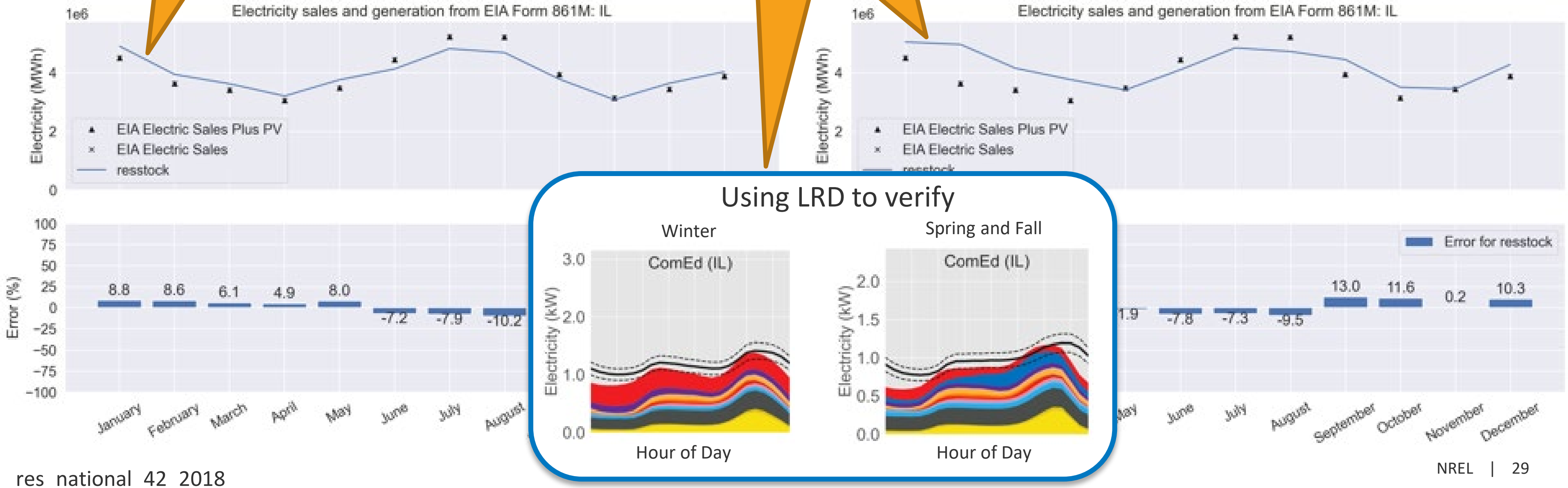
- **Not all states seem to be affected**

IL most likely uses calendar months

The winter, spring, and fall over prediction seems unlikely when using LRD

Before weighting function applied

After weighting function applied



res_national_42_2018

Residential stock end-use summary

ComEd, IL

City of Fort Collins, CO

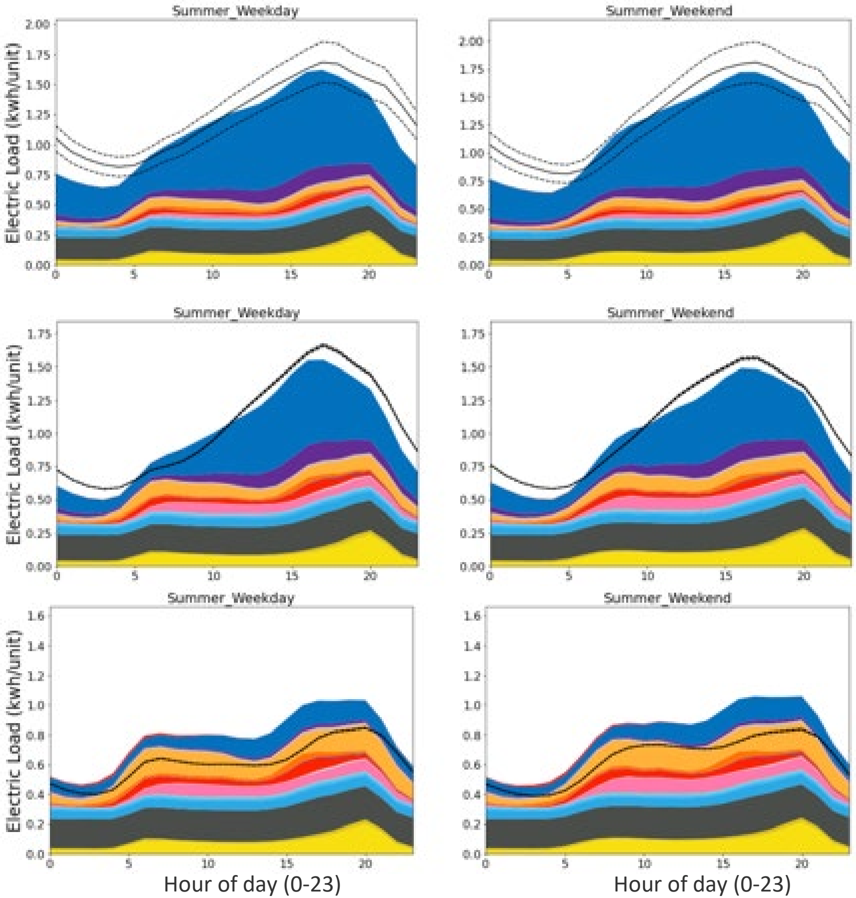
Seattle City Light, WA

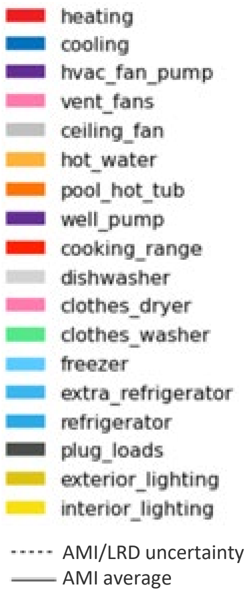
Seasonal end-use loads by day type

ComEd
service territory

City of Fort Collins
service territory

Seattle City Light
service territory





LRD uncertainty is 10%
AMI uncertainty is the standard error.

res_national_48_2018

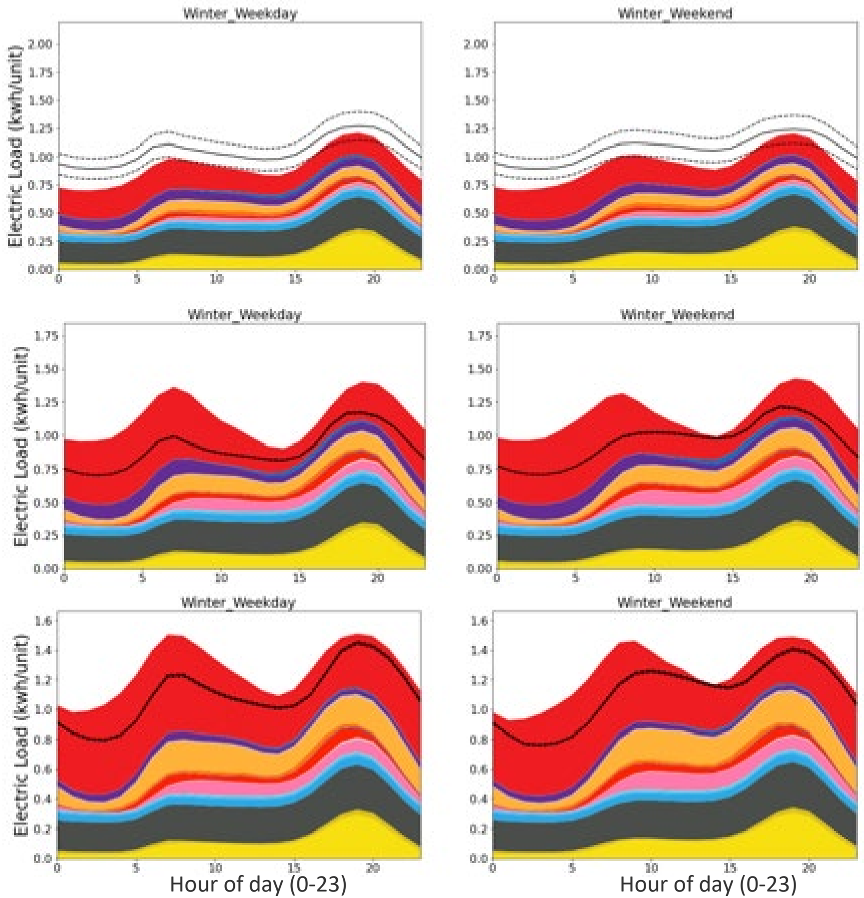
res_epb_scl_tal_48_2019

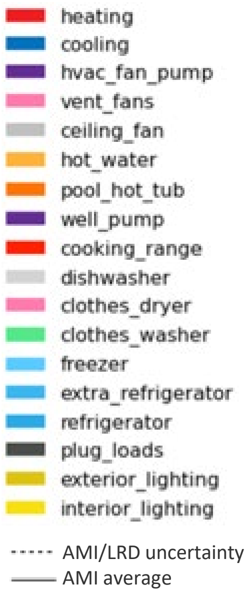
Seasonal end-use loads by day type

ComEd
service territory

City of Fort Collins
service territory

Seattle City Light
service territory





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res_national_48_2018

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Seasonal end-use loads by day type

ComEd
service territory

City of Fort Collins
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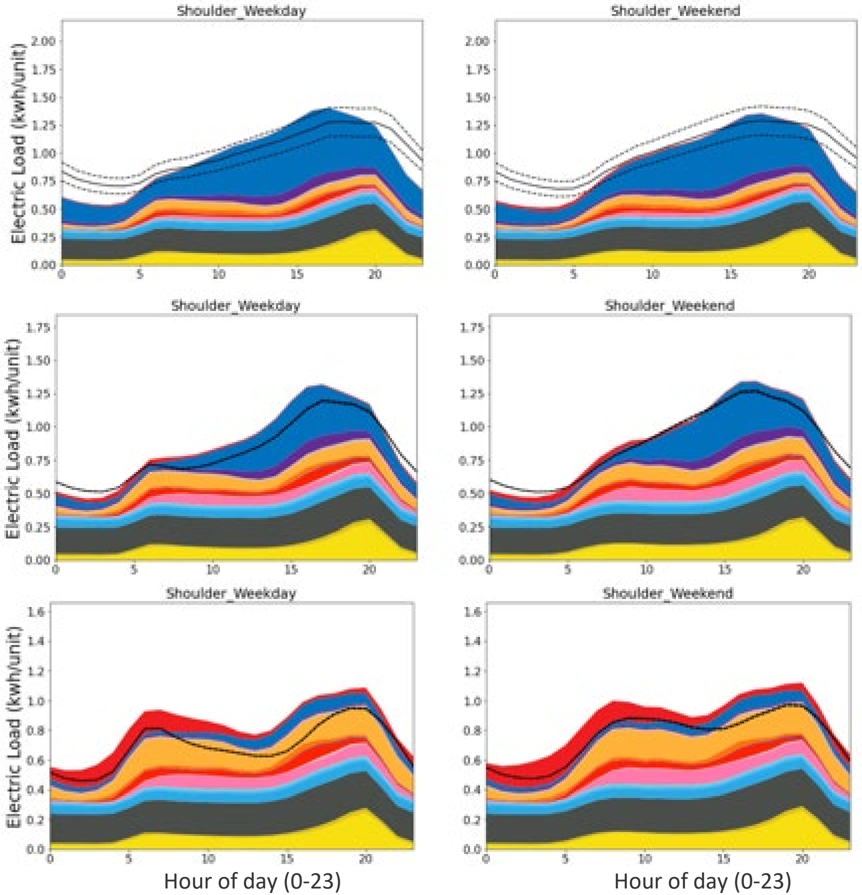
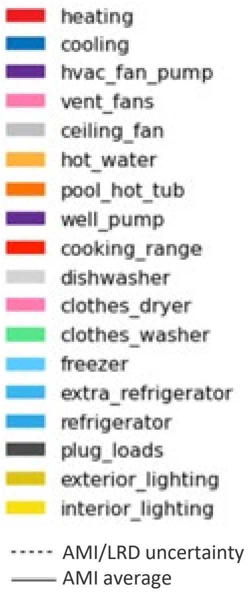
Seattle City Light
service territory





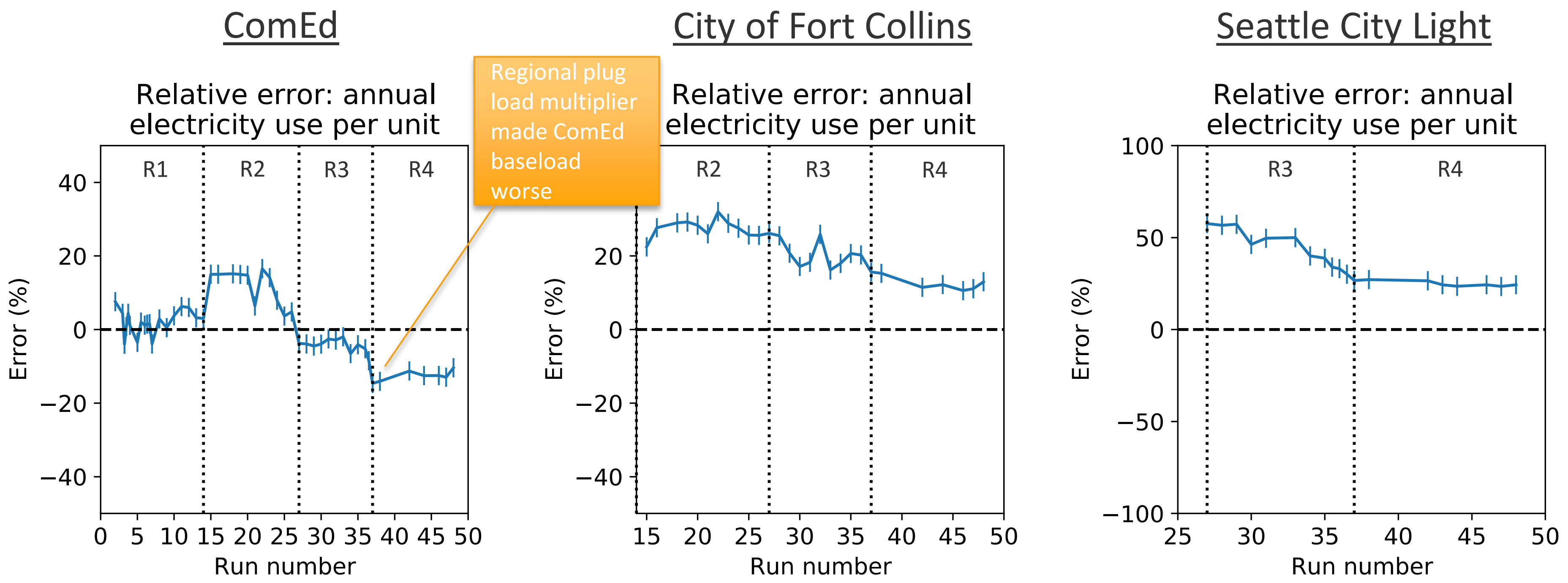
LRD uncertainty is 10%
AMI uncertainty is the standard error.

res_national_48_2018

res_epb_scl_tal_48_2019

Tracking Quantities of Interest

Annual error: previous calibration regions

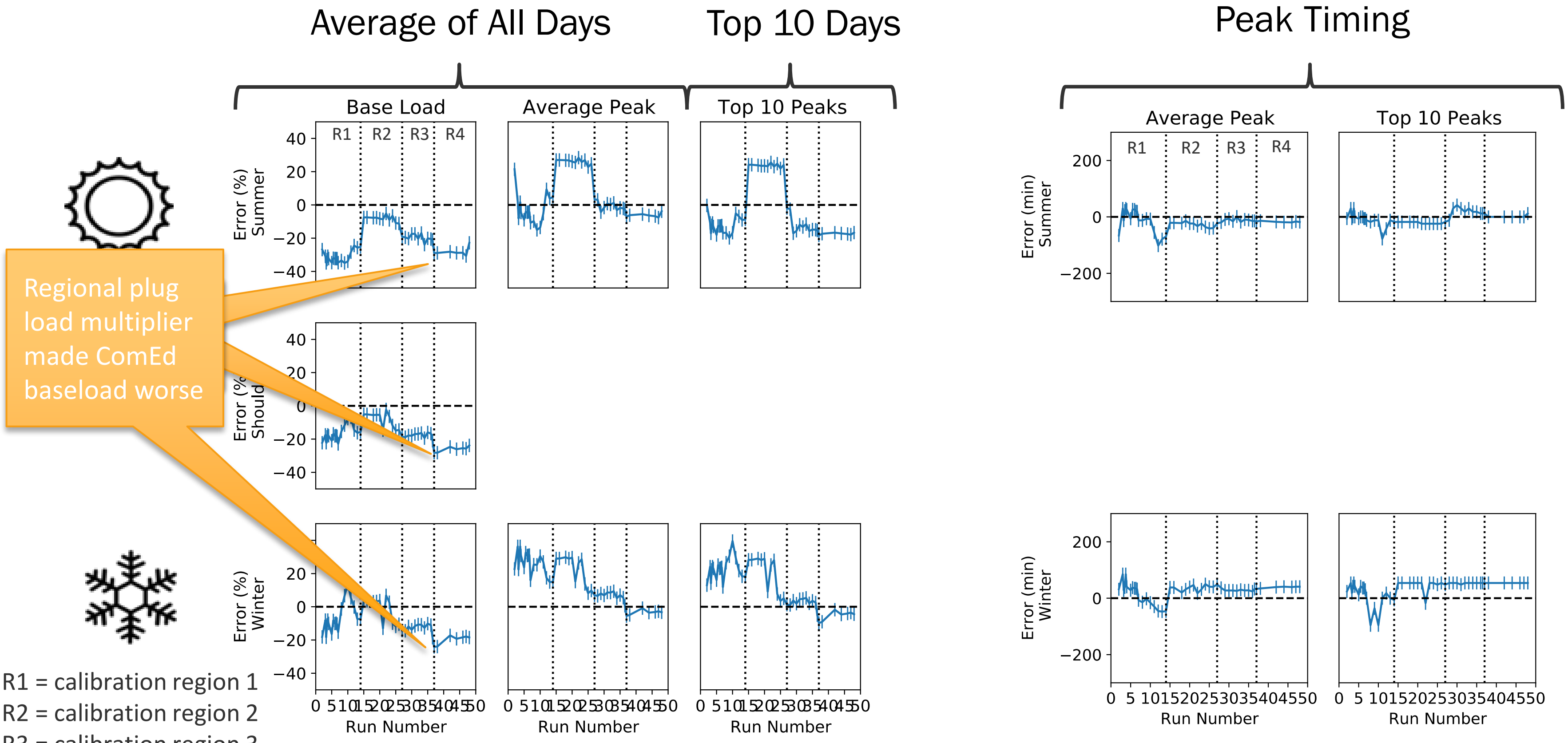


R1 = calibration region 1
R2 = calibration region 2
R3 = calibration region 3
R4 = calibration region 4

Reasons

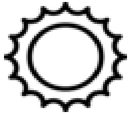
- Fort Collins and Seattle: Electric heating load too high
- ComEd: Low evening and early morning load

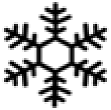
ComEd service territory: shape error metrics

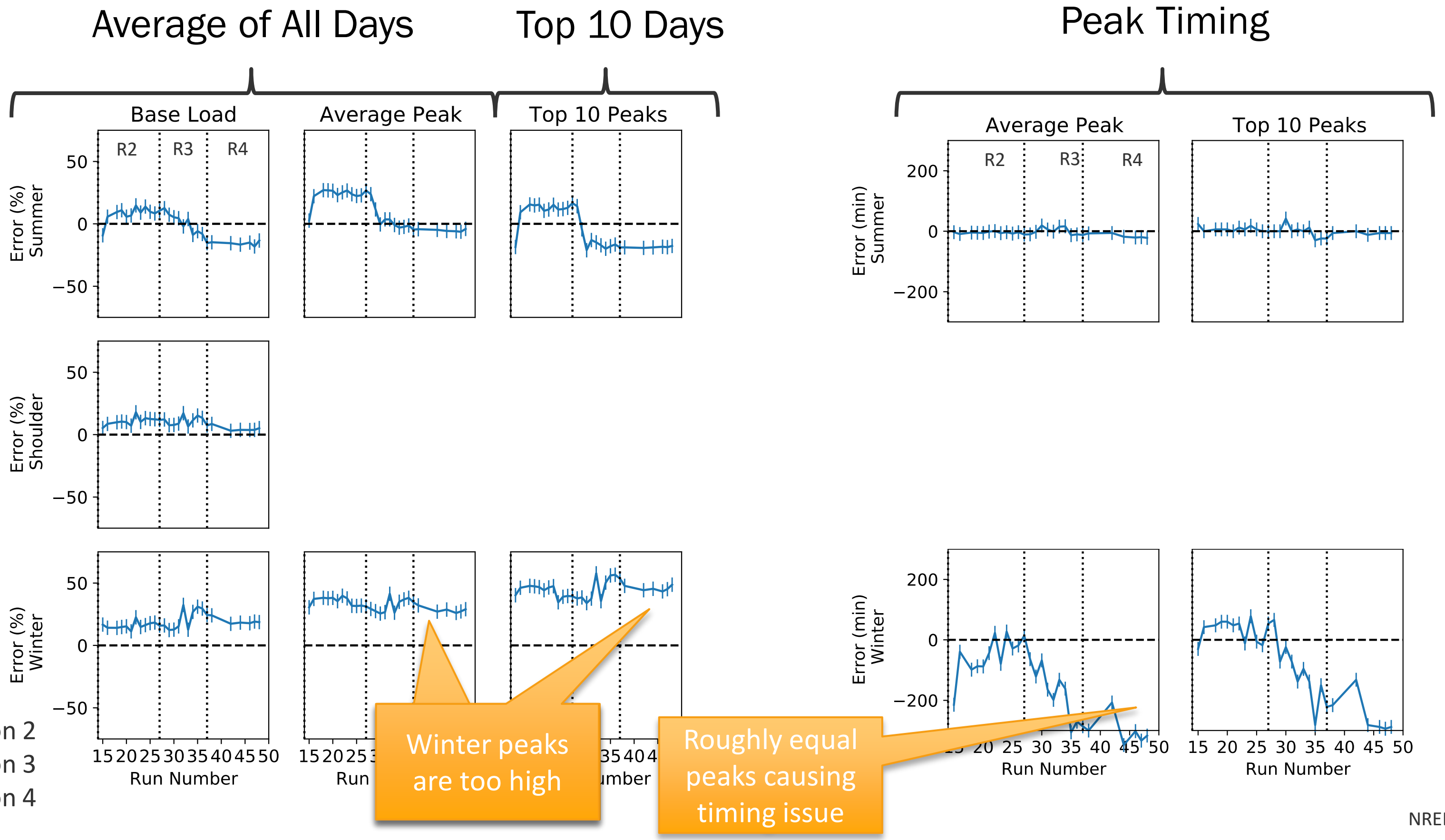


R1 = calibration region 1
R2 = calibration region 2
R3 = calibration region 3
R4 = calibration region 4

City of Fort Collins service territory: shape error metrics

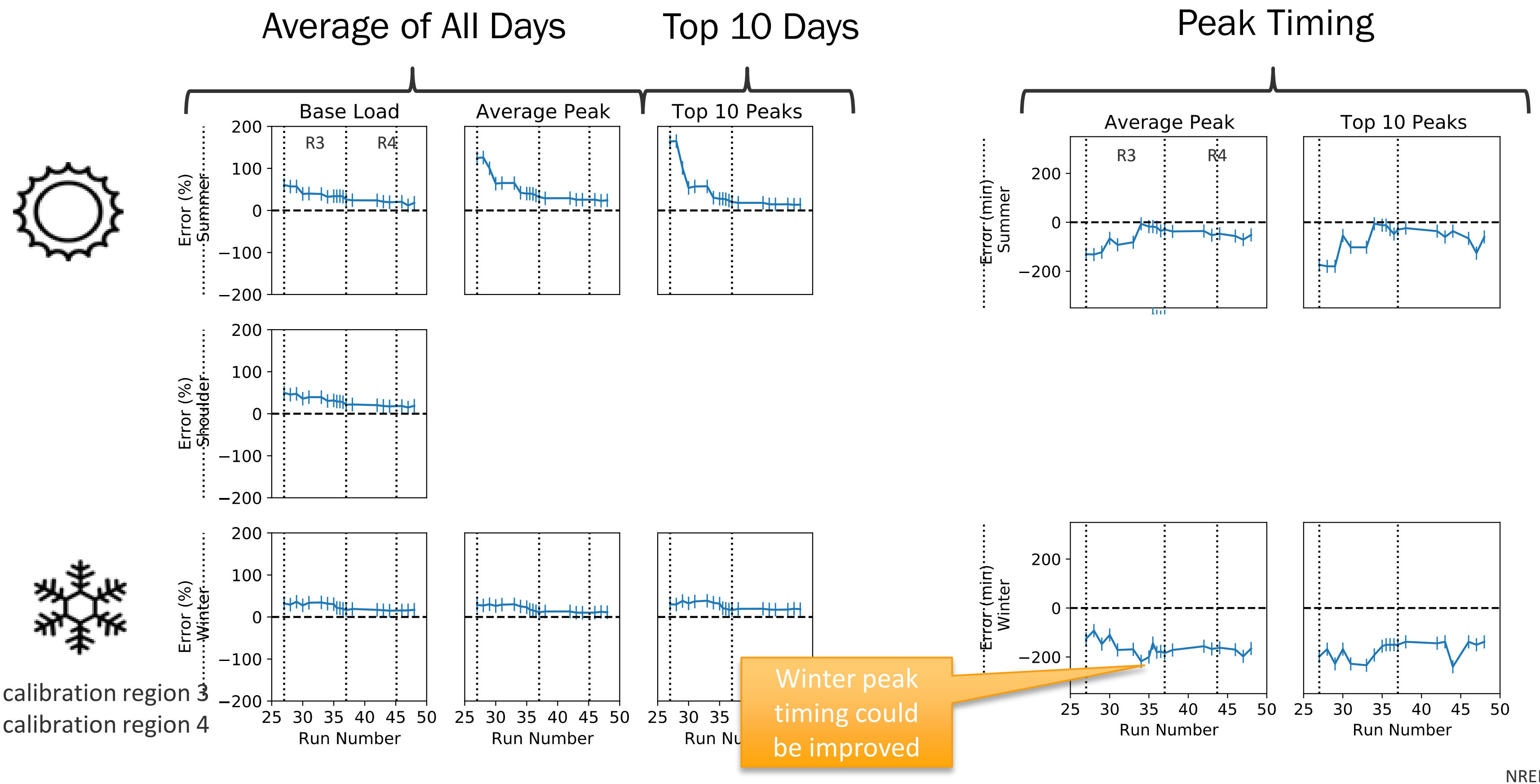






R2 = calibration region 2
R3 = calibration region 3
R4 = calibration region 4

Seattle City Light service territory: shape error metrics



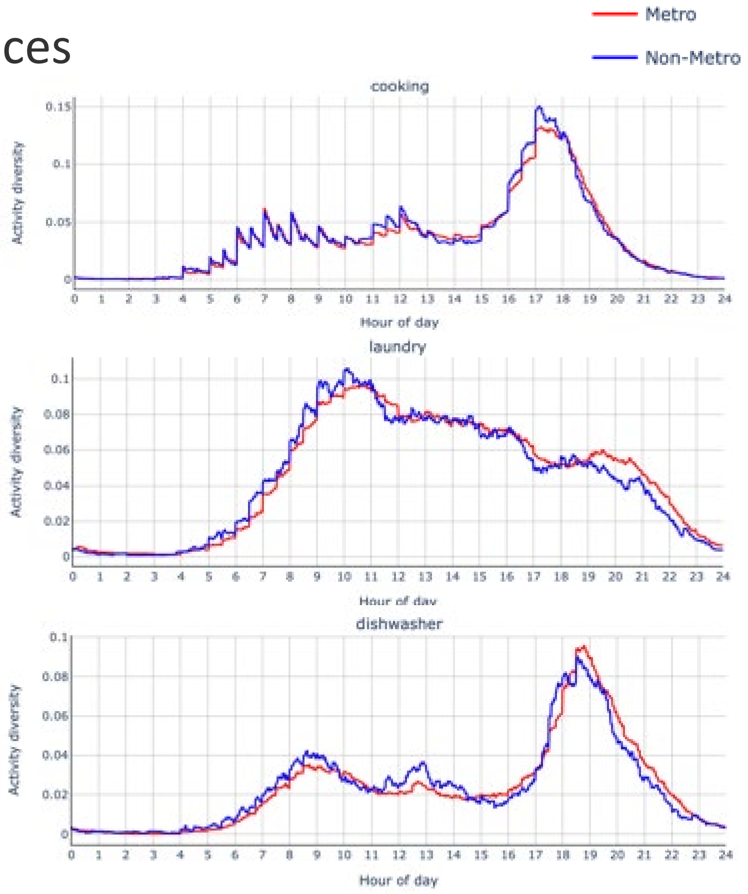
R3 = calibration region 3
R4 = calibration region 4

Baseload Updates

Update: Baseload schedule shifting using American Time Use Survey (ATUS)

- Investigated urban vs. rural schedule differences

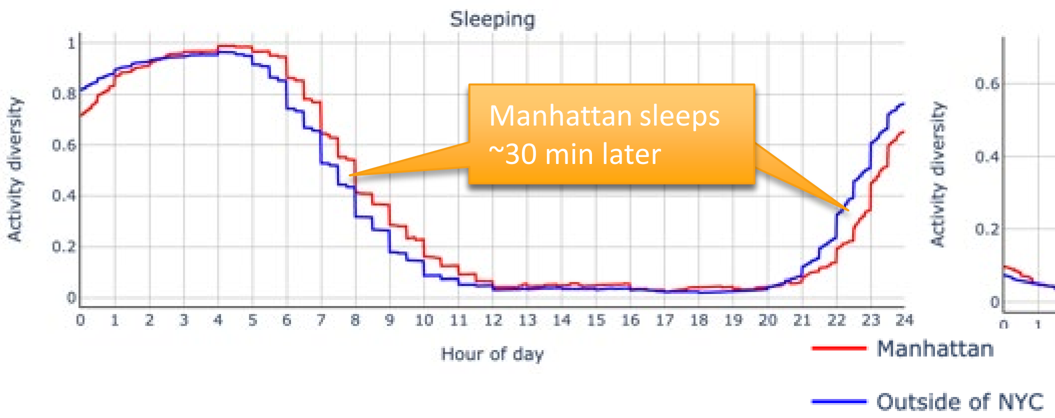
No significant difference in schedules between MSA and non-MSAs

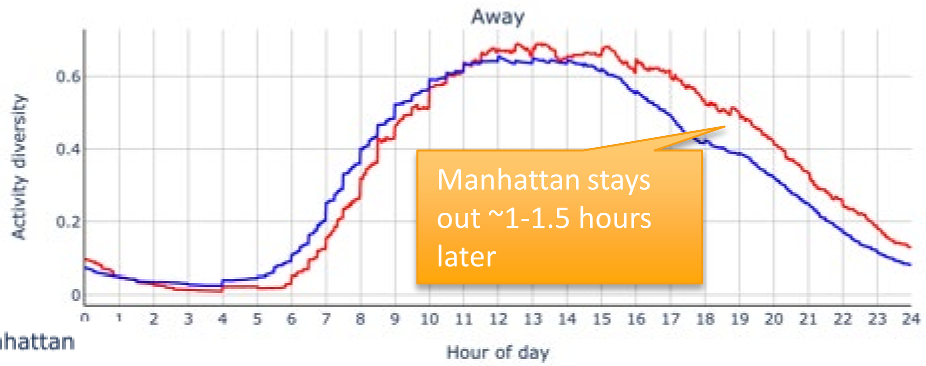


Metro: All counties belonging to an MSA in the U.S.
Non-Metro: All counties not belonging to an MSA in the U.S.

Update: Baseload schedule shifting using American Time Use Survey (ATUS)

- Investigated urban vs. rural schedule differences
  - Manhattan vs. New York state outside of New York City
- Downtown areas may have different schedule than the rest of the MSA
- MSAs are counties or multiple counties which may dilute behavior with suburban or even rural areas
- Low samples sizes in ATUS makes other activity comparisons difficult

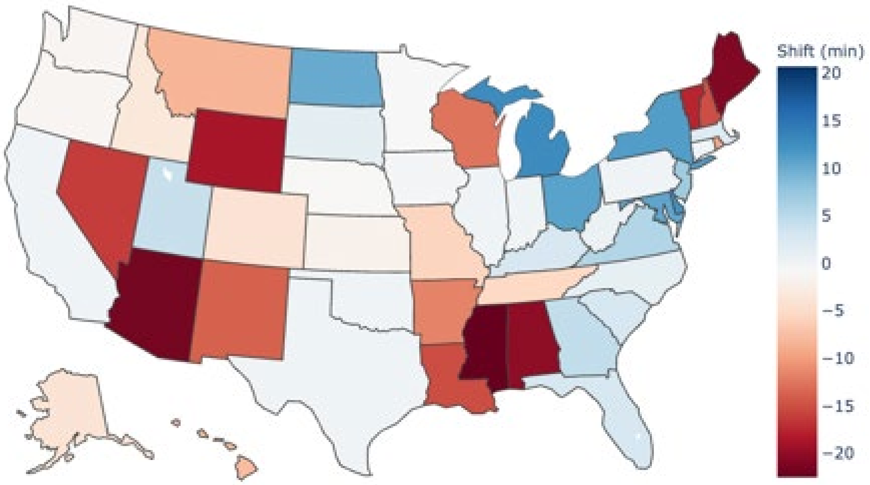




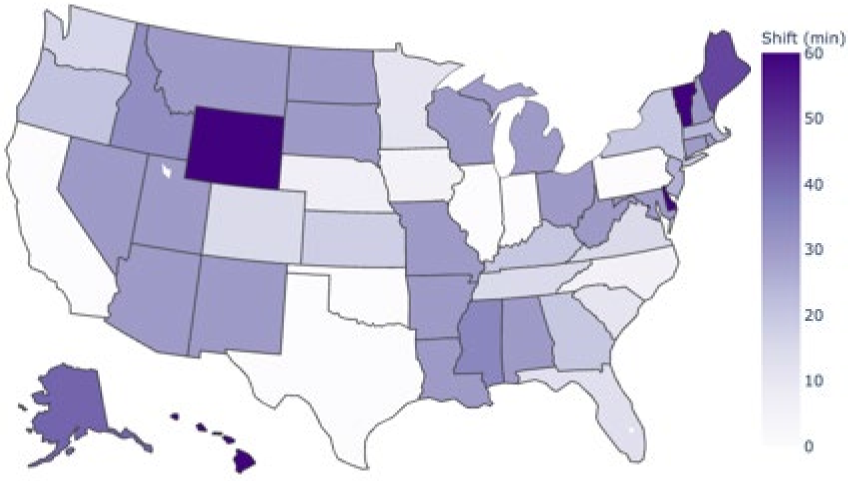
Update: Baseload schedule shifting using American Time Use Survey (ATUS)

- State and month schedule lead/lags from national average
- Calculated cross-correlation with the national average schedule

Average weekday baseload shift

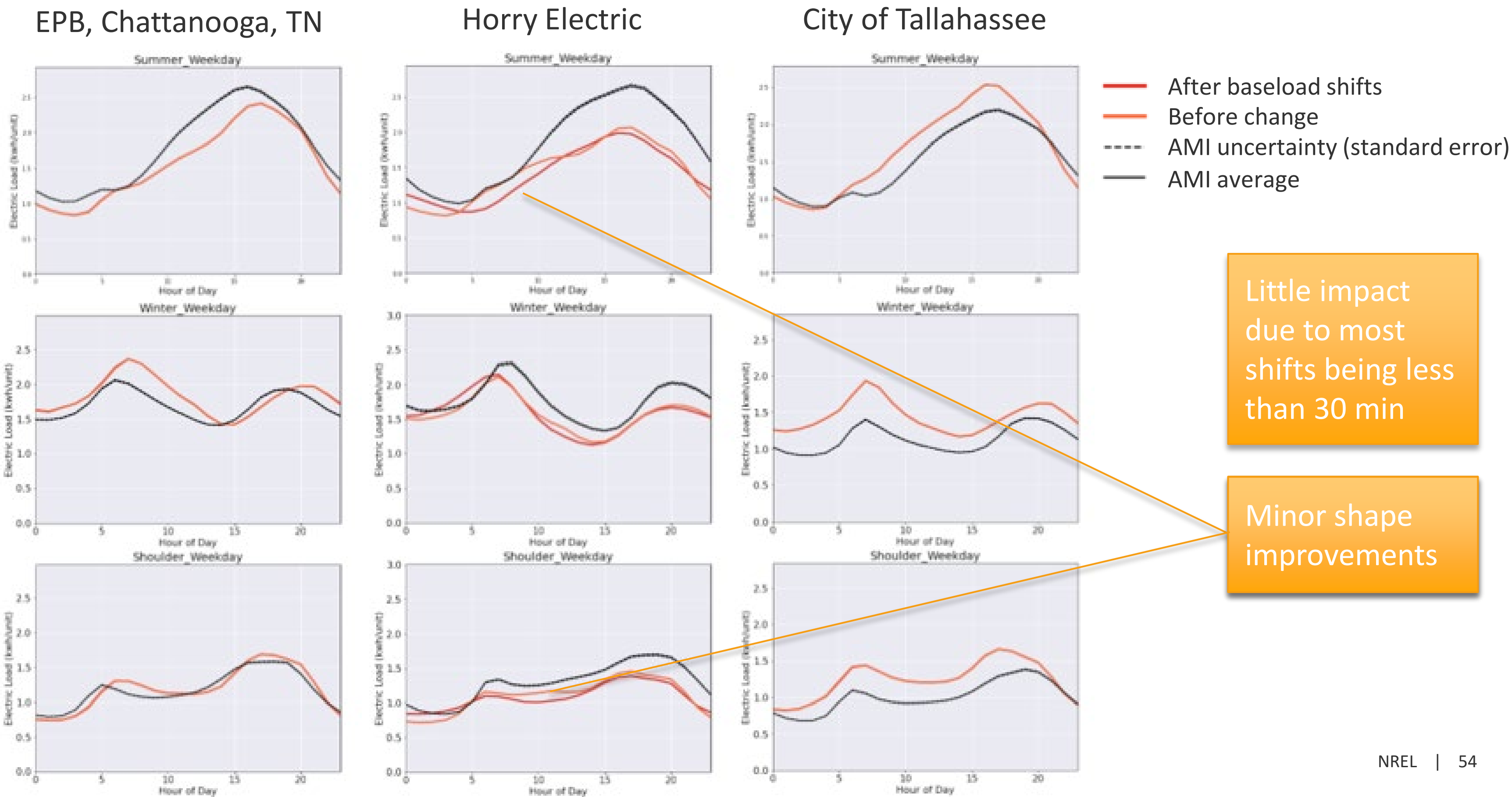


Maximum weekday baseload shift



** All shifts are relative to the national average baseload schedule*
** Positive shift (forward in time), negative shift (backward in time)*

Impact: Baseload schedule shifting using American Time Use Survey (ATUS)



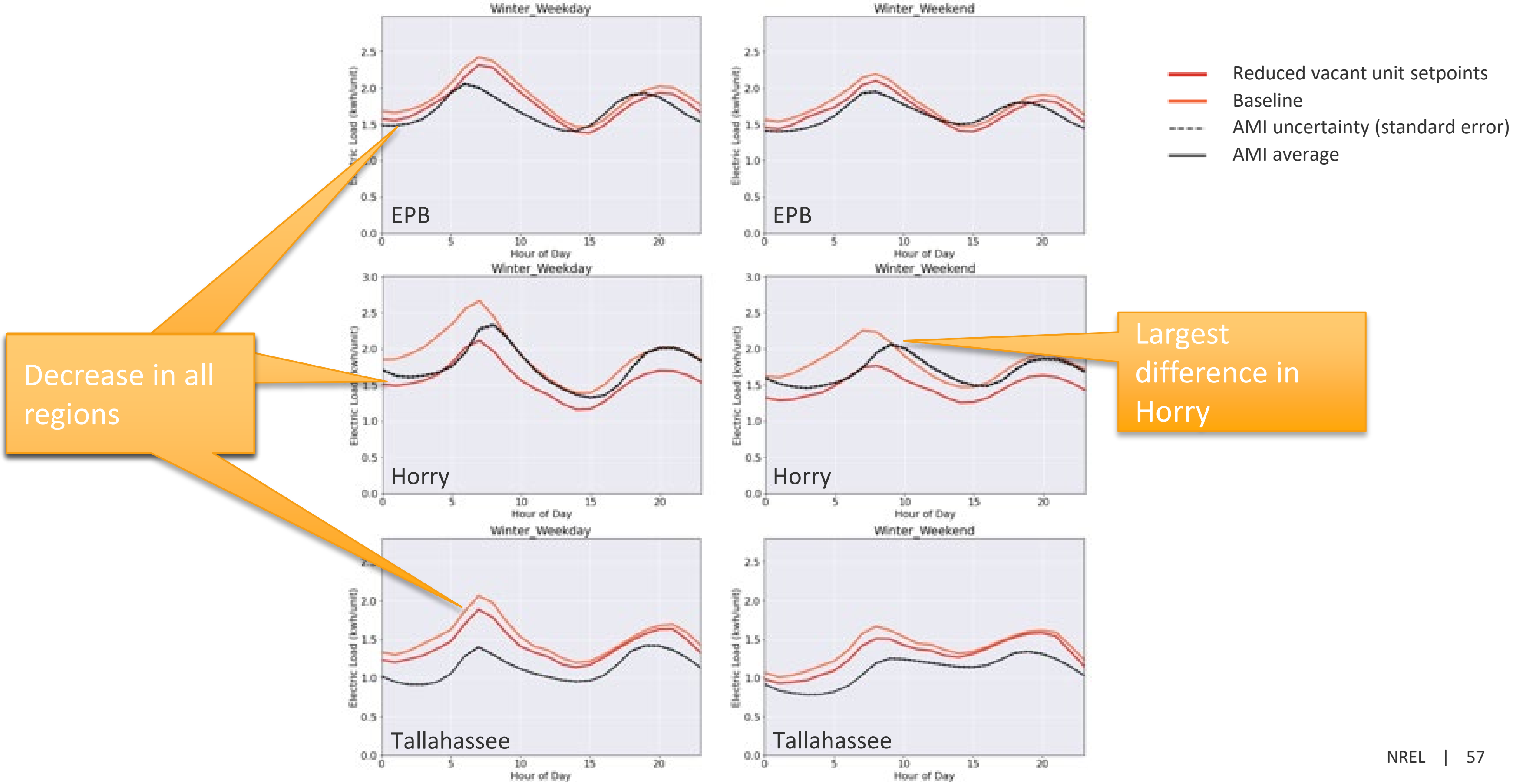
HVAC Updates

Update: Vacant Unit Heating Setpoints

- Vacant units are empty
- Heating is largest modeled electric load for vacant units

- <u>New Assumption</u>
  – Reduce vacant unit heating setpoints to 55 °F
  – Approach is “don't freeze the pipes” instead of using occupied setpoints.

Impact: Vacant Unit Heating Setpoints



Update: Zonal Electric Heating Setpoints

- NEEA's 2011 Residential Building Stock Assessment has evidence that homes with **baseboard or plug-in electric heaters** use less heating energy than homes with electric furnaces.
- This could be explained by lack of duct losses for baseboard/plug-in heating, but modeling in the region has overpredicted baseboard/plug-in heating, which suggests a different cause, such as "zonal" temperature control in different rooms.
- *Source*: "SEEM RBSA Calibration, Phase II – Electric Heating Energy Adjustments due to Supplemental Heat, Program Eligibility, and Related Factors." RTF Staff Technical Report. 2013. https://nwcouncil.app.box.com/s/51k80odysyf5hmpd6g9swr7g6y0cvxsv

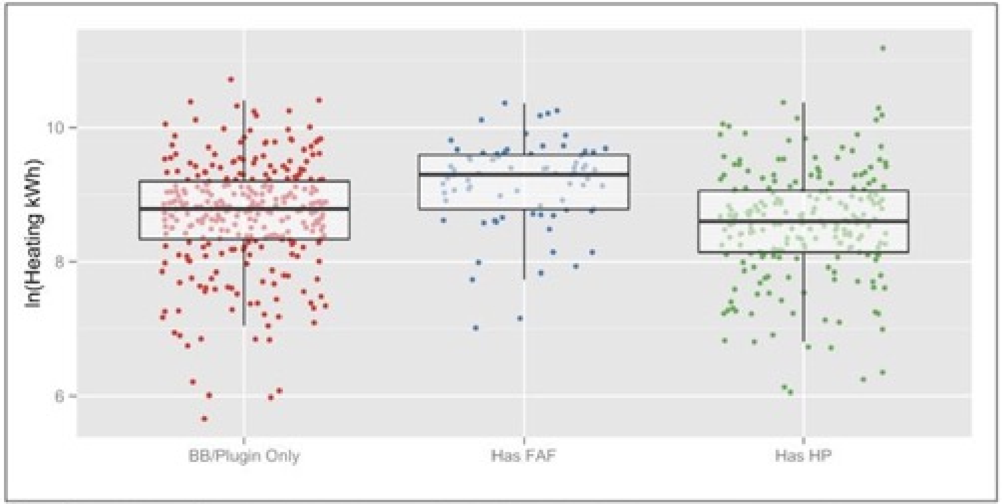
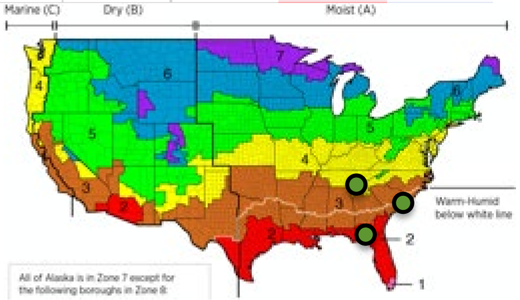


Figure 3. Distribution of heating kWh by heat source. The dark bars inside the boxes represent group medians; group means are very close to the medians for this data.

Update: Zonal Electric Heating Setpoints

We found that RECS 2009 data on heating setpoints for zonal electric heating are **lower on average** than ducted electric furnaces/heat pumps

IECC Climate Zone	% of electric heat that is zonal	Avg. heating temp. when home					Avg. heating temp. at night					Avg. heating temp. when gone				
		Before	After		Difference		Before	After		Difference		Before	After		Difference	
			Zonal electric	All others	Zonal electric	All others		Zonal electric	All others	Zonal electric	All others		Zonal electric	All others	Zonal electric	All others
1A-2A	10%	71.5	69.7	71.6	-1.8	0.1	70.3	68.0	70.5	-2.3	0.2	68.8	65.3	69.1	-3.5	0.3
2B	10%	71.3	73.7	71.1	2.4	-0.2	69.8	67.5	69.9	-2.3	0.1	69.0	70.8	68.8	1.8	-0.2
3A	8%	71.1	71.3	71.0	0.2	-0.1	69.5	68.1	69.6	-1.4	0.1	68.0	65.2	68.1	-2.8	0.1
3B-4B	31%	69.7	67.3	70.0	-2.4	0.3	67.2	65.0	67.4	-2.2	0.2	65.0	62.7	65.2	-2.3	0.2
3C	55%	66.7	65.8	66.8	-0.9	0.1	63.2	63.8	63.1	0.6	-0.1	60.8	61.4	60.7	0.6	-0.1
4A	20%	69.8	68.5	69.9	-1.3	0.1	68.1	67.5	68.2	-0.6	0.1	67.0	63.6	67.2	-3.4	0.2
4C	64%	67.3	65.9	68.3	-1.4	1.0	63.8	63.3	64.2	-0.5	0.4	62.5	60.1	64.1	-2.4	1.6
5A	54%	68.9	68.2	68.9	-0.7	0.0	66.9	66.7	66.9	-0.2	0.0	66.0	63.9	66.2	-2.1	0.2
5B-5C	34%	69.0	67.0	69.1	-2.0	0.1	66.5	65.8	66.6	-0.7	0.1	65.1	60.2	65.4	-4.9	0.3
6A-6B	52%	68.8	68.6	68.8	-0.2	0.0	66.6	67.4	66.6	0.8	0.0	65.9	65.1	65.9	-0.8	0.0



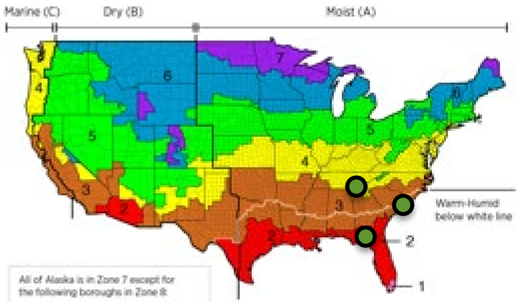
2A, 3A, and 4A are the IECC climate zones corresponding to Tallahassee, Horry, and Chattanooga

Update: Zonal Electric Heating Setpoints

We added a dependency on zonal electric heating to our heating setpoint and setback distributions queried from RECS 2009.

Base at-home heating setpoint distribution

Dependency =Vacancy Status	Dependency =ASHRAE IECC Climate Zone 2004	Dependency =Geometry Building Type RECS	Dependency =HVAC Has Zonal Electric	Option =55F	Option =60F	Option =62F	Option =65F	Option =67F	Option =68F	Option =70F	Option =72F	Option =75F	Option =76F	Option =78F	Option =80F	sample_weight	sample_count
Occupied	2A	Single-Famil	No	0%	2%	1%	5%	3%	20%	23%	17%	15%	5%	7%	1%	9527435.45	1090
Occupied	3A	Single-Famil	No	0%	2%	0%	7%	3%	24%	22%	17%	13%	4%	6%	2%	10269769.4	901
Occupied	4A	Single-Famil	No	0%	2%	2%	8%	6%	28%	24%	19%	8%	1%	1%	1%	15959650.5	1716
Occupied	2A	Single-Famil	Yes	0%	16%	0%	13%	0%	12%	31%	7%	15%	1%	5%	1%	722695.87	77
Occupied	3A	Single-Famil	Yes	0%	2%	0%	9%	0%	7%	33%	23%	14%	2%	6%	4%	369640.28	31
Occupied	4A	Single-Famil	Yes	0%	8%	0%	15%	1%	28%	25%	3%	13%	3%	0%	3%	882617.64	84

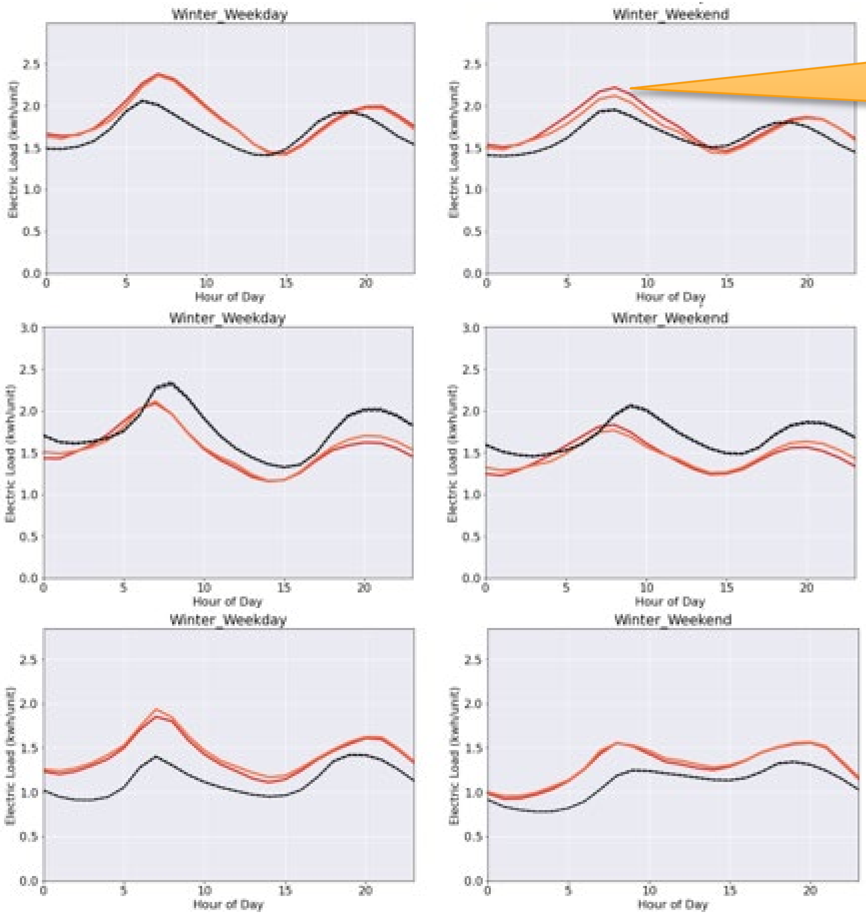


Impact: Zonal Baseboard Heating Setpoints

Total Stock
EPB, Chattanooga, TN

Total Stock
Horry Electric

Total Stock
Tallahassee, FL



Some locations are slightly worse, but minor impact

Minor impact may be due to higher central setpoints with lower baseboard setpoints

- After change
- Before change
- AMI uncertainty (standard error)
- AMI average

Update: Room AC Cooling Setpoints

- California's 2009 Residential Appliance Saturation Study (RASS) breaks out Room AC setpoints from other cooling types

Non-room AC systems have approximately the same setpoints

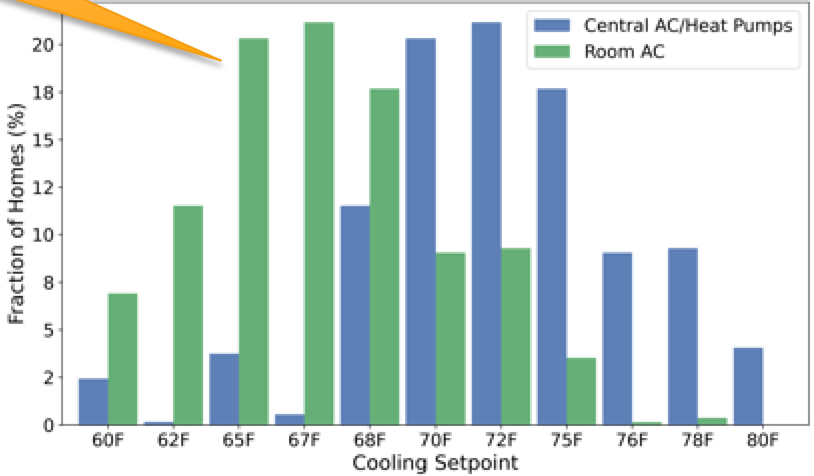
ResStock now accounts for lower room AC setpoints

Cooling Setpoint (9am – 5pm): RASS 2009

Main HVAC System Cooling Type	<70F	70F-73F	74F-76F	77F-80F	>80F
Central AC	8.0%	19.0%	25.5%	36.4%	11.1%
Evaporative Cooler	13.2%	16.5%	25.9%	35.1%	9.2%
Heat Pump	11.6%	29.2%	20.4%	33.4%	5.4%
Room AC	41.4%	53.0%	4.4%	1.3%	0.0%

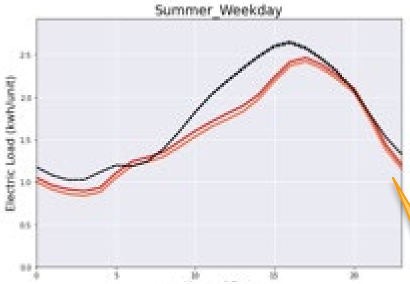
Room AC setpoints ~6F cooler than other systems

Integrating lower room AC setpoints in ResStock

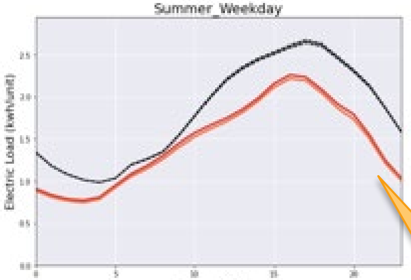


Impact: Room AC Cooling Setpoints

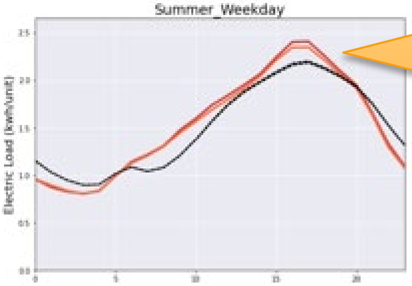
Total Stock
EPB, Chattanooga, TN



Total Stock
Horry Electric, SC



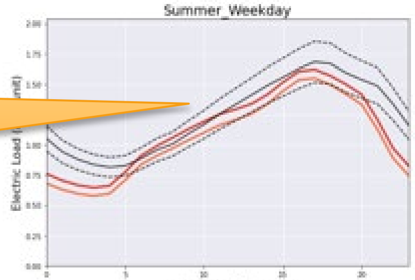
Total Stock
Tallahassee, FL



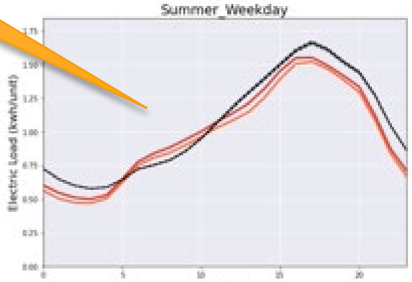
Hour of day (0-23)

Larger impact in ComEd and City of Fort Collins

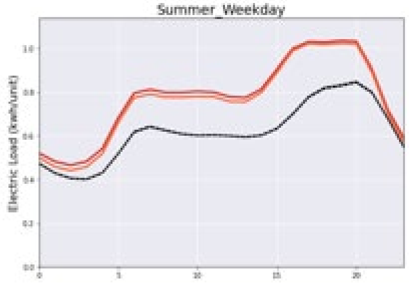
Little change in Southeast due to high saturation of central AC systems



Total Stock
ComEd, IL



Total Stock
City of Fort Collins, CO



Total Stock
Seattle City Light, WA

Hour of day (0-23)

Areas for Improvement

Next Region: Likely Areas for Improvement

Changes underway

- Continue improving correction model
- Improve data on multifamily building heights
- Improve data source for masonry vs. wood framed walls (esp. important for Northeast)
- Incorporate on-site PV generation in models

Potential areas for Region 5 (may not get to all items on list)

- Introduce partial space heating to reduce electric heating loads
- Incorporate saturation of existing ductless heat pumps (esp. important for Northeast)
- Improve data source for duct leakage
- Improve geographic resolution for 1980s-2000s insulation data
- Investigate how setpoints change seasonally (using Ecobee data)

Residential Poll Questions

End-Use Load Profiles for the U.S. Building Stock: Project Recap

Eric Wilson

April 21, 2021

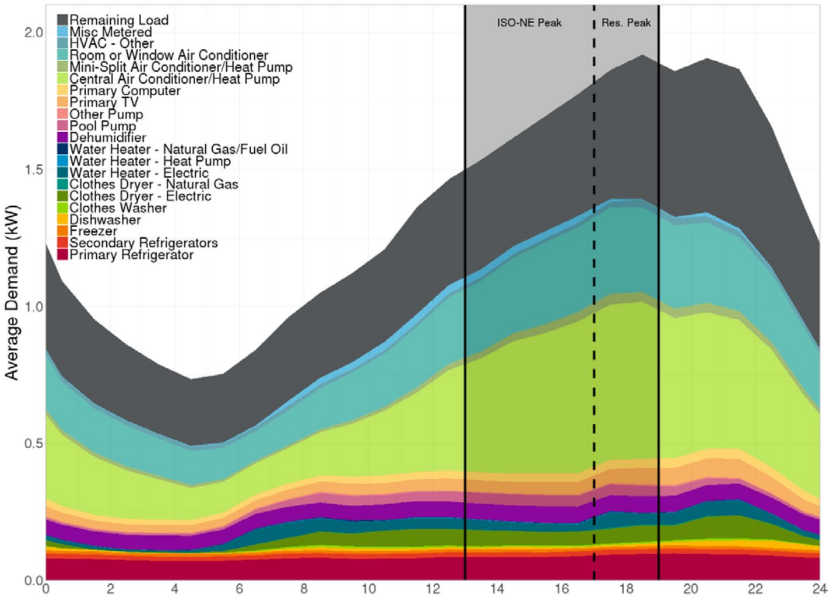
What is an End-Use Load Profile?

End-use load profiles…

- describe ***how*** and ***when*** energy is used

End-use load/savings profiles are…

- the **most essential data resource currently missing** for Time-Sensitive Valuation of Energy Efficiency
- needed for R&D prioritization, utility resource and distribution system planning, state and local energy planning and regulation
- **critical for widespread adoption** of grid-interactive and efficient buildings.



Source: Navigant Massachusetts RES 1 Baseline Load Shape Study

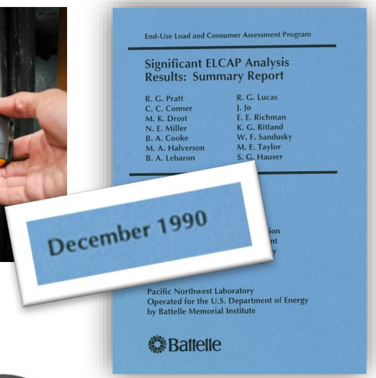
Challenge & Opportunity

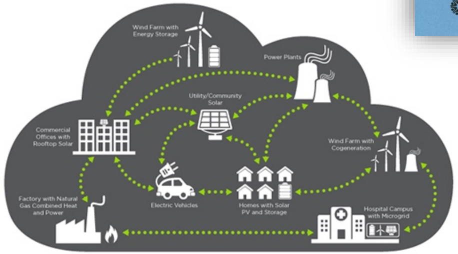
Challenge

- Existing end-use load profiles are often outdated and limited to certain regions and building types because of the high cost of traditional end-use sub-metering.
- They are insufficient for accurate evaluation of numerous emerging use cases of grid-interactive and efficient buildings.

Opportunity

- New ResStock™ and ComStock™ models statistically represent energy use of U.S. buildings.
- Models produce hourly end-use load profiles, <u>but prior calibration efforts focused on annual energy use.</u>





Source: Navigant

ResStock

ComStock

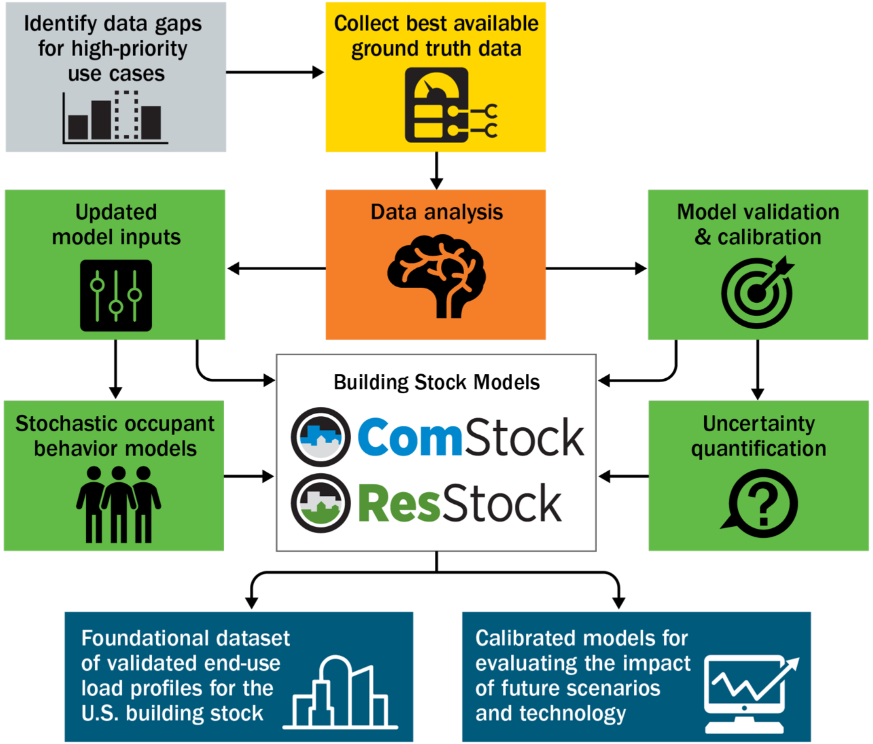
Solution: A Hybrid Approach (1)

Hybrid approach combines best-available ground-truth data—

- submetering studies,
- whole-building interval meter data, and
- other emerging data sources

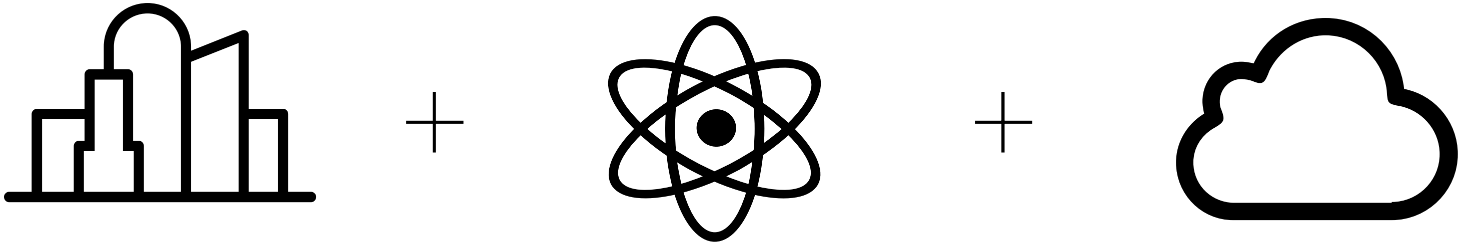
—with the reach, cost-effectiveness, and granularity of physics-based and data-driven building stock modeling capabilities

The novel approach delivers a nationally-comprehensive dataset at a fraction of the historical cost.



Project Outcomes | Calibrated Building Stock Models

ComStock ResStock



- DOE-funded, NREL-developed models of the U.S. building stock
- 100,000s of statistically representative physics-based building energy models (BEM)
- Use DOE’s BEM tools OpenStudio and EnergyPlus
- Produce hourly load profiles, but calibration to-date has focused on annual energy consumption

Project Outcomes | Working List of End Uses

Commercial

- HVAC
  - Heating
  - Cooling
  - Fans
  - Pumps
  - Heat rejection
  - Humidification
  - Heat recovery
- Service water heating
- Refrigeration
- Plug and process loads
- Lighting
  - Interior
  - Exterior

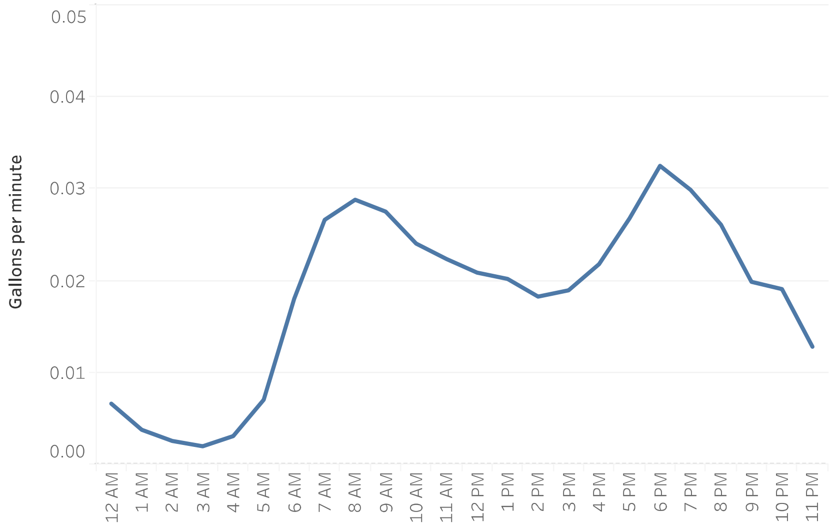
Residential

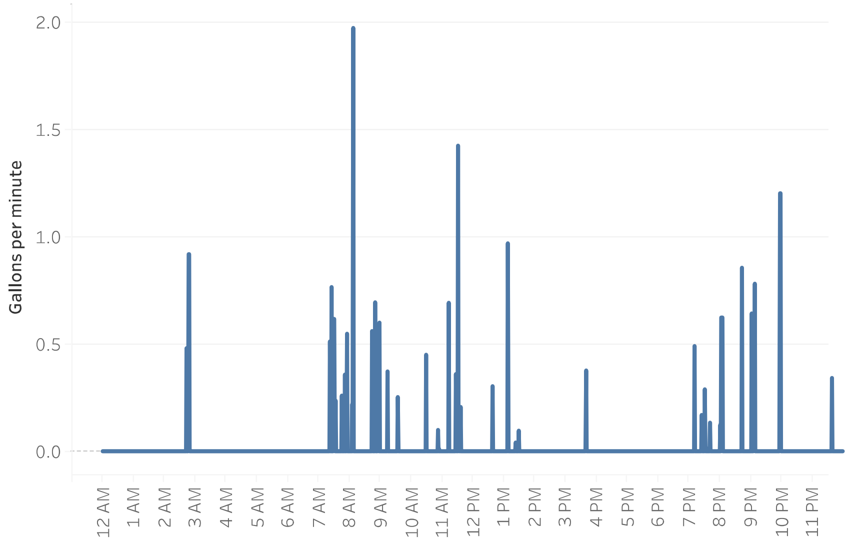
- HVAC
  - Heating
  - Cooling
  - Furnace/Air-conditioning
  - Boiler pumps
  - Ventilation fans
- Domestic water heating
- Major appliances
  - Refrigerator
  - Clothes washer
  - Clothes dryer
  - Dishwasher
  - Cooking range
  - Pool/spa pumps & heaters
- Miscellaneous plug loads
- Lighting
  - Interior
  - Exterior

Project Outcomes | Working List of Building Types

Commercial	Residential
• Small Office	• Single-Family Detached
• Medium Office	• Single-Family Attached
• Large Office	• Multifamily low-rise
• Stand-alone Retail	• Multifamily mid-rise
• Strip Mall	• Multifamily high-rise
• Primary School	
• Secondary School	
• Outpatient Healthcare	
• Hospital	
• Small Hotel	
• Large Hotel	
• Warehouse (non-ref.)	
• Quick Service Restaurant	
• Full Service Restaurant	
• Supermarket	

Project Outcomes| Aggregate and Individual Load Profiles





Example aggregate versus individual EULP concept demonstration using water draws

Project Team

NREL
Transforming ENERGY

BERKELEY LAB
Lawrence Berkeley
National Laboratory

Argonne
NATIONAL LABORATORY

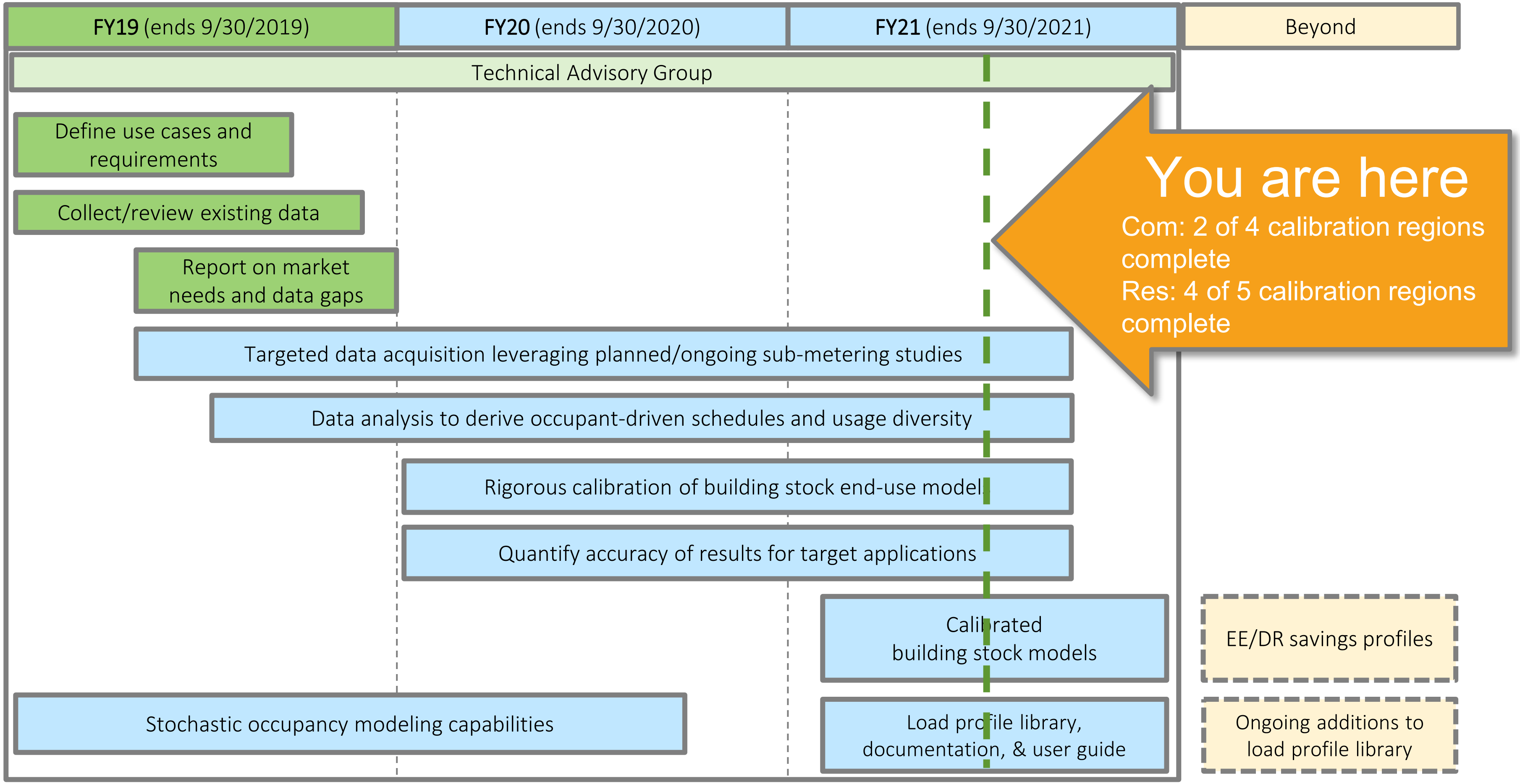
EPRI | ELECTRIC POWER RESEARCH INSTITUTE

neep
Northeast
Energy
Efficiency
Partnerships

Stakeholder Engagement

In-kind participation by 65 advisory group members

Project Timeline

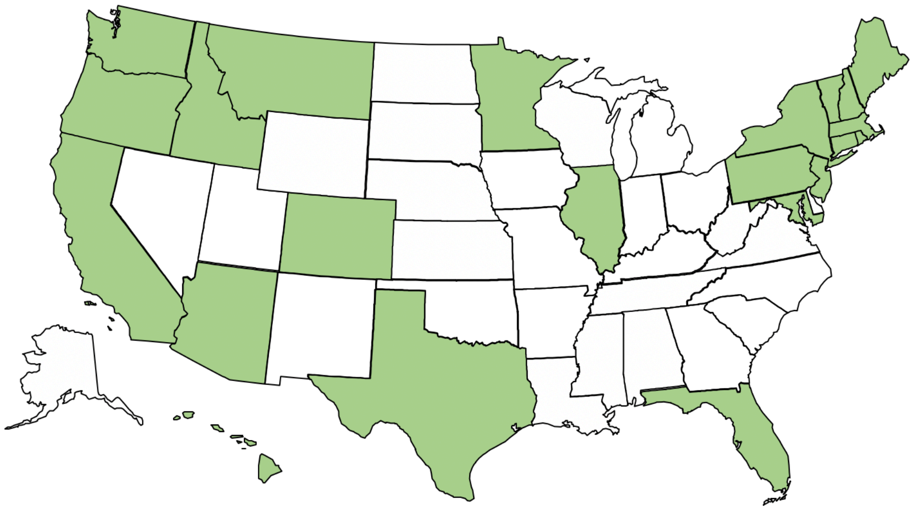


Market Needs and Use Cases

Year One Report is Available

End Use Load Profiles for the U.S. Building Stock: Market Needs, Use Cases and Data Gaps is available now

Market Needs | Existing Publicly Available End Use Load Profiles



States with Publicly Available End-Use Load Profile Data*

- We developed an inventory of publicly available end-use load profiles.
- The inventory is now available on LBNL's website: https://emp.lbl.gov/publications/end-use-load-profile-inventory

*There are significant differences in the number of load profiles available in each state. See the inventory for more detail.

Market Needs| Use Case Identification

- Use cases: type of process or analysis that utilize end-use load profiles
- The project team and technical advisory group brainstormed and prioritized use cases
- 10 most mentioned use cases are presented in the report
  - Electricity Resource Planning
  - Energy Efficiency Planning
  - Policy and Rate Design
  - Transmission and Distribution System Planning
  - Program Impact Evaluation
  - Demand-Response Planning
  - Improved Building Energy Modeling
  - Electrification Planning
  - Emissions Analysis
  - PV Planning
- Use cases informed data requirements for modeling

Use Cases | Data Fidelity Requirements

Use Case Data Requirements

Use Case	Time Resolution	Geographic Resolution	Electrical Characteristics
Electricity Resource Planning	Hourly or peak day	Service territory	Real power
Energy Efficiency Planning	Hourly or peak day	Service territory	Real power
Policy and Rate Design	15 min to hourly	City, climate zone, or state	Depends on application
Transmission and Distribution System Planning	15 min or smaller	Distribution feeder	Real and reactive power
Program Impact Evaluation	Hourly	Service territory	Real power
Demand-Response Planning	15 min to hourly	Service territory	Real power
Improved Building Energy Modeling	15 min	Region	Real power
Electrification Planning	Hourly	Service territory or smaller	Real power
Emissions Analysis	Hourly	Service territory or larger	Real power
PV Planning	1 min	Weather station	Real power

Use Cases | Data Fidelity Requirements

Time Resolution

15-minute

- Highest impact cases require only hourly results
- PV Planning is the only top use case that requires less than 15-minute data

Geographic Resolution

~~Utility territory~~
County

- Distribution System Planning requires feeder-level data
- A "mix-and-match" approach from a bank of load profiles could help build specific utility and feeder level information

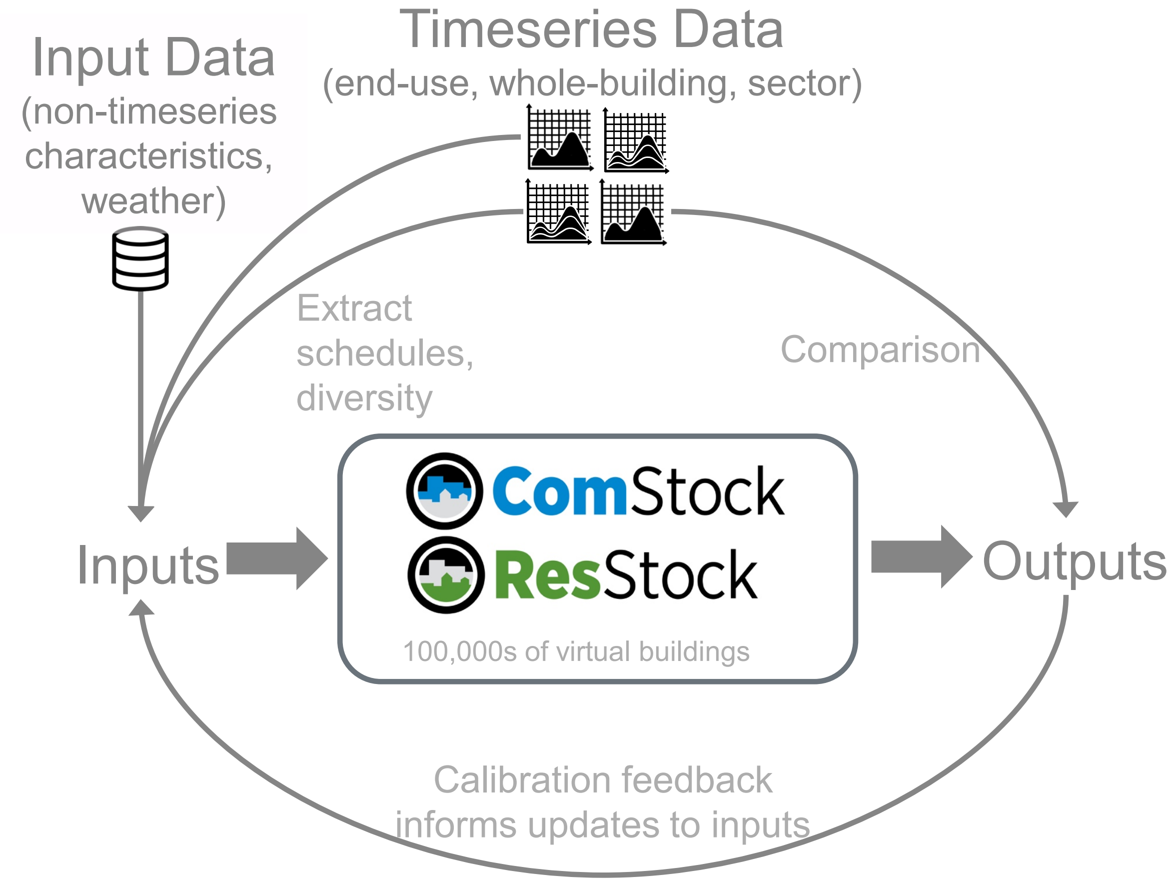
Electrical Characteristics

Real power

- Some distribution system planning use cases might benefit from reactive power
- Data requirements for some use cases are not well understood

Data Needs and Identified Gaps

How are we using data?



Model Calibration Data

Summary of Calibration Data Classes

Type of Calibration Data	Summary of Availability
Utility Sales: Annual sales/consumption data by sector by utility	Universally available from U.S. Energy Information Administration (EIA)
Load research data: Utility customer class aggregate load shapes	Acquired for ~20 utility companies and the Electric Reliability Council of Texas
Advanced metering infrastructure (AMI): Whole-building AMI data joined with building characteristic metadata	Acquiring in multiple census divisions, via nondisclosure agreements with utility companies
Submetered: End-use metering data, including smart thermostat data	Multiple (3+) strong data sets available for residential; few data sets available for commercial buildings

Addressing Data Gaps

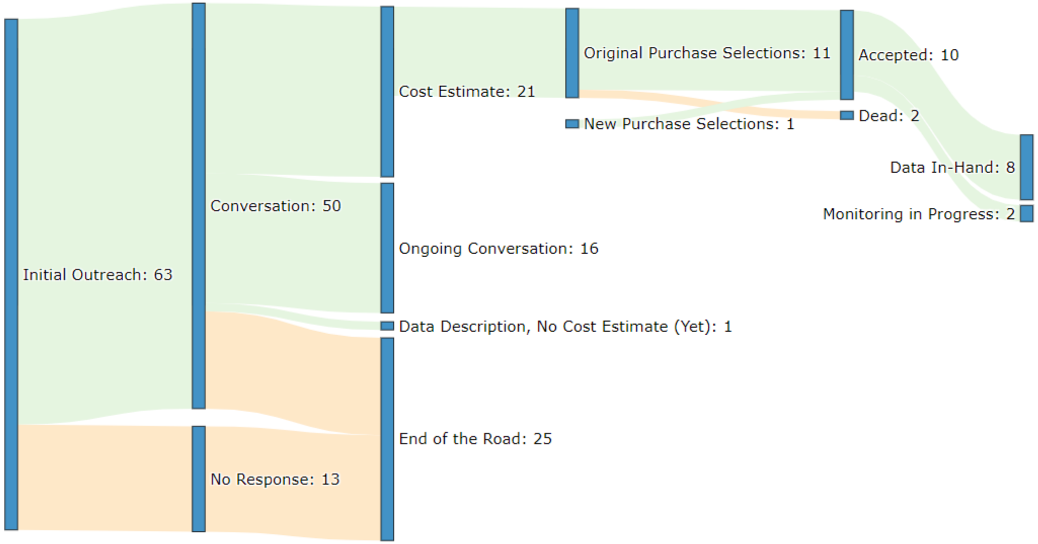
From the initial data collection, the largest identified gap was submetered data for commercial buildings

To address this gap, we:

1. Conducted a targeted market research effort to identify data sets for potential purchase (BAS data, EM&V studies, etc.)
2. Are studying transferability between building types and regions

Commercial End-Use Data Procurement

- Summary
  - Major outreach effort, >700 hours
  - 10 datasets purchased



Putting Our Industry's Data to Work: A Case Study of Large-Scale Data Aggregation

Preprint

Elaina Present,[1] Chris CaraDonna,[1] Eric Wilson,[1] Natalie Frick,[2] Janghyun Kim,[1] Rajendra Adhikari,[1] Anna C. McCreery,[3] and Elizabeth Titus[4]

1 National Renewable Energy Laboratory
2 Lawrence Berkeley National Laboratory
3 Elevate Energy
4 Northeast Energy Efficiency Partnerships

Presented at the 2020 ACEEE Summer Study on Energy Efficiency in Buildings
August 17-21, 2020

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-5500-77102
September 2020

https://www.nrel.gov/docs/fy20osti/77102.pdf

Sample Sizes: Weather-driven End Uses

Weather-driven	Proposed Minimum Sample Size[1]	Oct 31st Package Sample Size[2]	Procured Sample Size[3]
Heating	48	6218	**5176**
Cooling	48	6598	**5351**
Fans	21	2497	**328**
Pumps	21	500	**83**
Heat Rejection	21	21	**41**
Humidification	21	27	**22**
Heat Recovery	21	22	**36**
Refrigeration	21	1076	**1010**
Exterior Lighting	21	846	**846**

[1]Minimum sample size targets presented at subject matter expert webinar on 8/28/2019.
[2]Counts based on vendor rough estimates obtained during market outreach
[3]Procured Sample Size includes data in hand and data that is being contracted for procurement

No gaps identified

Sample Sizes: Schedule-driven End Uses

Schedule-driven		Hospital / Outpatient	Primary School / Secondary School	Full-Service Restaurant / Quick Service Restaurant	Retail / Strip Mall	Supermarket	Small Hotel / Large Hotel	Warehouse	Multifamily	Small Office / Medium Office / Large Office
Proposed Minimum Sample Size[1]	Interior Lighting	21	21	21	21	21	21	21	n/a	21
	Interior Equipment	21	21	21	21	21	21	21	n/a	21
	Service Water Heating	0	0	0	0	0	0	0	n/a	0
	Cooking	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Oct 31st Package Sample Size[2]	Interior Lighting	103	281	760	1046	137	53	270	20	337
	Interior Equipment	2	285	196	214	4	5	25	22	270
	Service Water Heating	0	0	316	106	0	0	0	0	1
	Cooking	0	2	2618	0	0	1	0	0	0
Procured Sample Size[3]	**Interior Lighting**	**76**	**162**	**710**	**800**	**71**	**42**	**131**	**65**	**118**
	Interior Equipment	**4**	**284**	**200**	**196**	**3**	**2**	**50**	**367**	**53**
	Service Water Heating	**0**	**0**	**317**	**107**	**1**	**0**	**15**	**98**	**1**
	Cooking	**0**	**0**	**2620**	**1**	**1**	**0**	**0**	**0**	**0**

[1] *Minimum sample size targets presented at subject matter expert webinar on 8/28/2019.*
[2] *Counts based on vendor rough estimates obtained during market outreach*
[3] *Procured Sample Size includes data in hand and data that is being contracted for procurement*

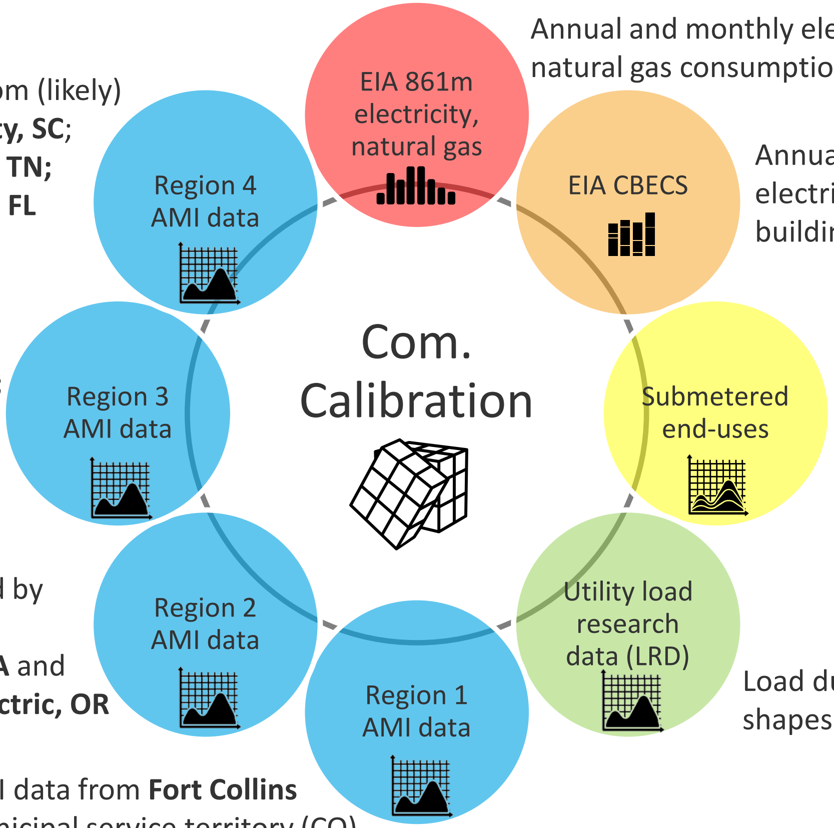
=gap

Commercial Calibration Dimensions

Annual and monthly electricity and natural gas consumption by state, sector

AMI data from (likely) **Horry County, SC**; **Chatanooga TN; Tallahassee, FL**

Annual gas and electricity EUIs by building type



AMI data from **Vermont; Maine; Cherryland, MI**

Sub-metered end-use load data (10 datasets)

AMI data (aggregated by building type) from **Seattle City Light, WA** and **Portland General Electric, OR**

Load duration curves and seasonal load shapes of ~16 utilities around U.S.

AMI data from **Fort Collins** municipal service territory (CO)

Residential Calibration Dimensions

Annual electric sales of all utilities in U.S.

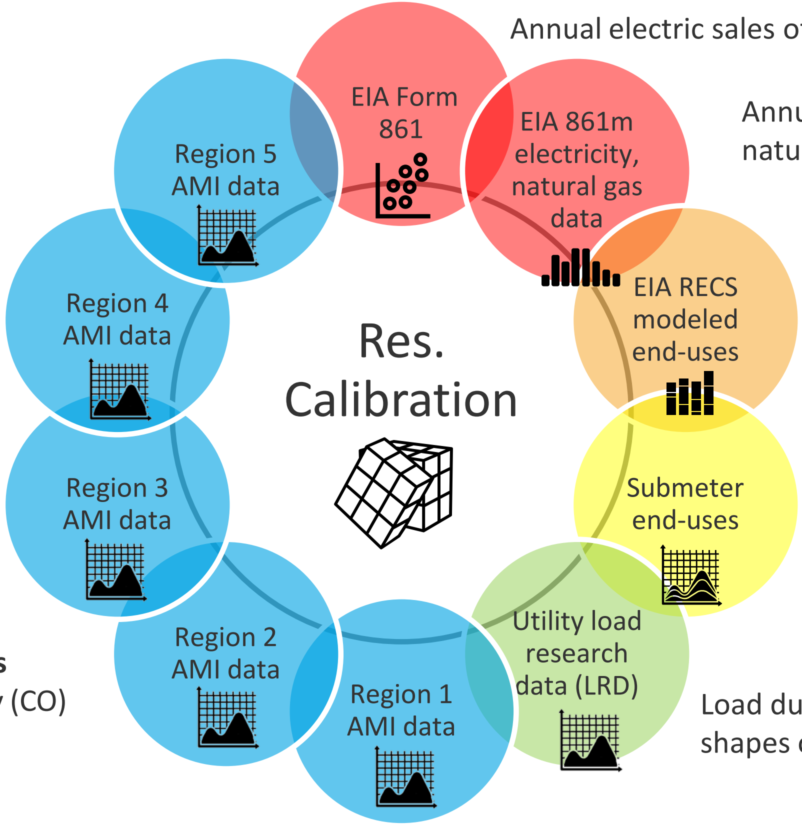
AMI data from **Vermont; Cherryland, MI**

Annual and monthly electricity and natural gas consumption by state, sector

AMI data from Electric Power Board of **Chattanooga, TN Horry Electric (SC),** and City of **Tallahassee, FL**

Annual end-use loads of occupied dwelling units

- Building type
- Climate zone
- Fuel (electricity, natural gas, propane, fuel oil)



AMI data (aggregated by building type) from **Seattle City Light, WA**

Sub-metered end-use load data (5 datasets)

AMI data from **Fort Collins** municipal service territory (CO)

Load duration curves and seasonal load shapes of ~16 utilities around U.S.

Advanced metering infrastructure (AMI) data from **ComEd** service territory (IL)

Uncertainty quantification framework

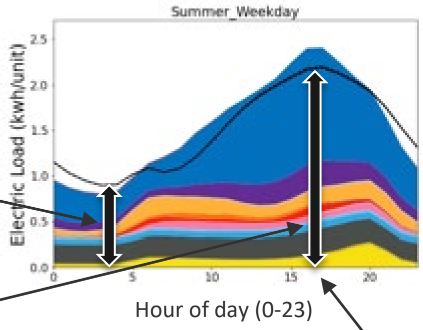
“Quantities of Interest” = Key Model Outputs

- Quantities to be primary focus for calibration
- Outputs that will contain uncertainty bounds

Quantities of Interest (QOI)

by building type and region

- Annual energy use (MWh)
- Average daily minimum magnitude (MW)
  - Summer, All days
  - Winter, All days
  - Shoulder, All days
- Average daily maximum magnitude (MW)
  - Summer, All days
  - Summer, Top 10 days
  - Winter, All days
  - Winter, Top 10 days
  - Shoulder, All days

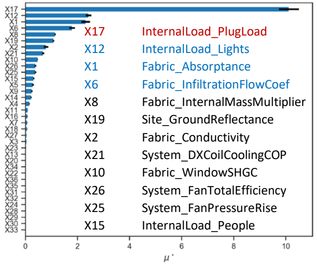


- Average daily maximum load timing (hour of day)
  - Summer, All days
  - Summer, Top 10 days
  - Winter, All days
  - Winter, Top 10 days
  - Shoulder, All days

Sensitivity Analyses

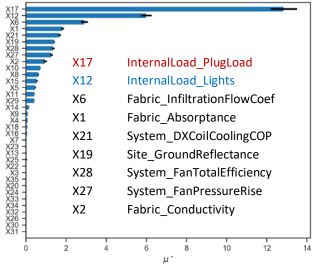
Ranking of Critical EnergyPlus Inputs

LA



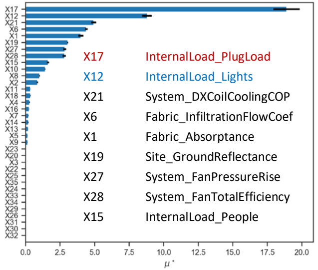
Stock average: 33.34GJ

Chicago



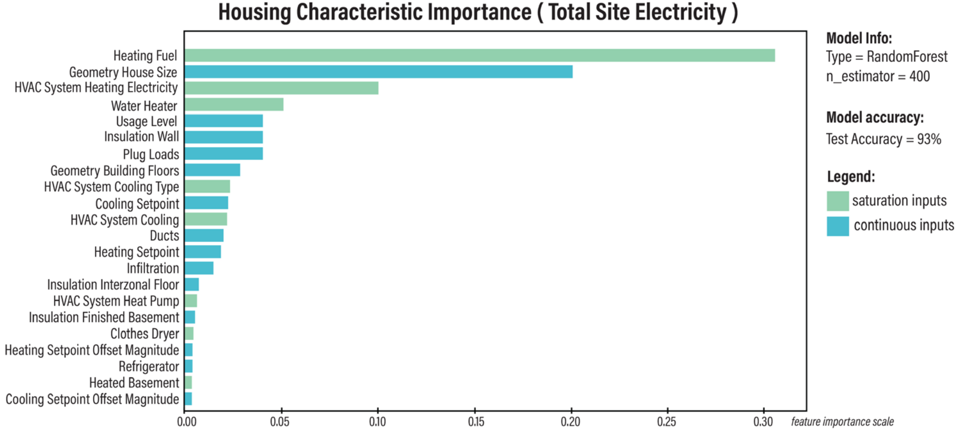
Stock average: 100.00GJ

Miami



Stock average: 162.09GJ

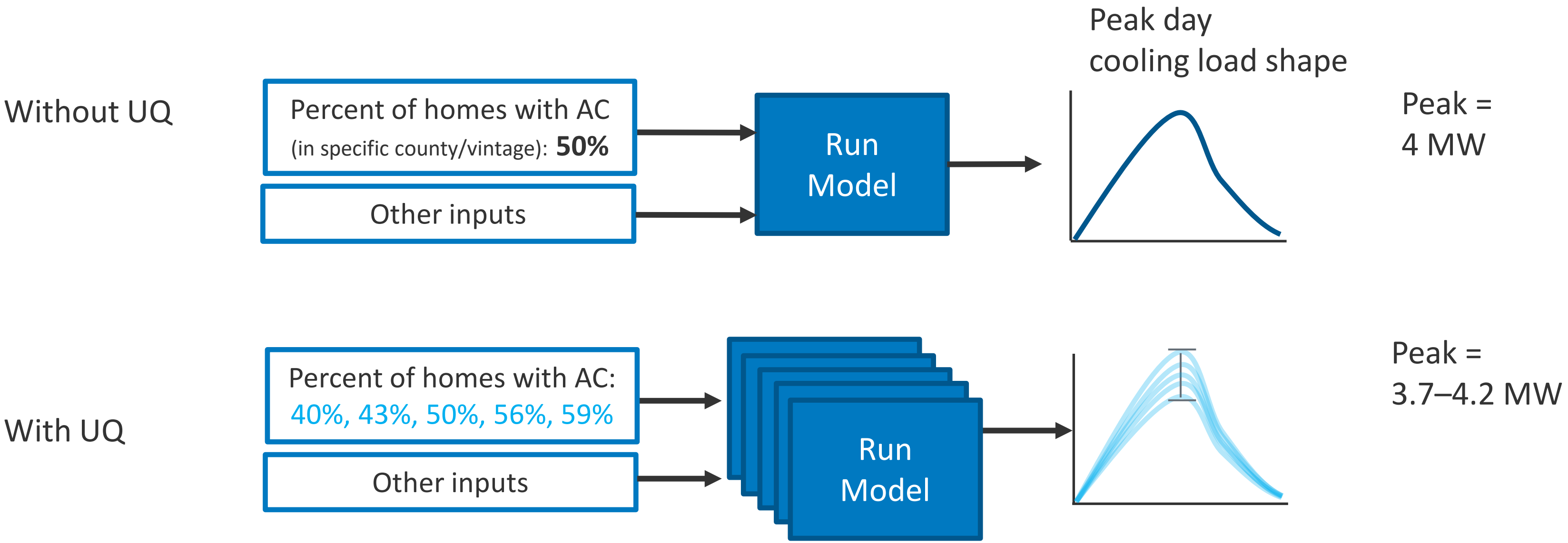
Ranking of ResStock / ComStock Inputs



Argonne NATIONAL LABORATORY

NREL

Uncertainty Quantification (UQ)



The uncertainty range is propagated through the model to determine uncertainty of outputs

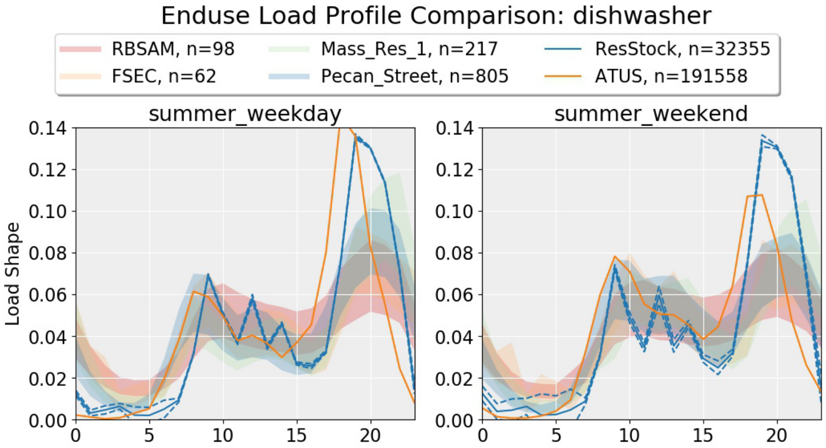
Residential end-use transferability study

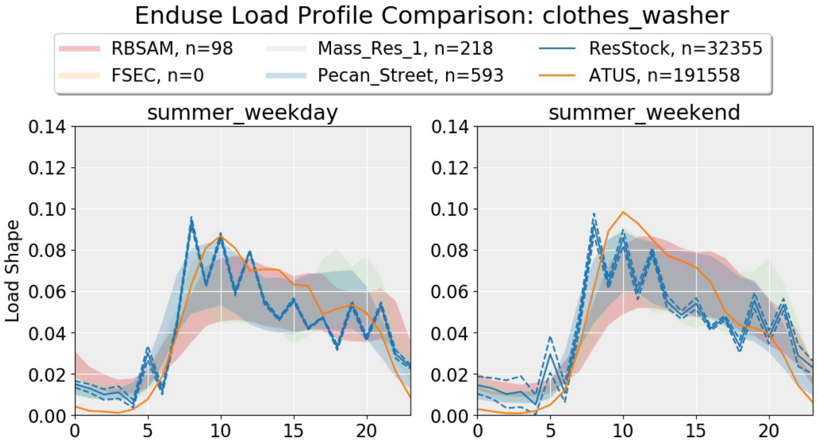
Residential end use transferability

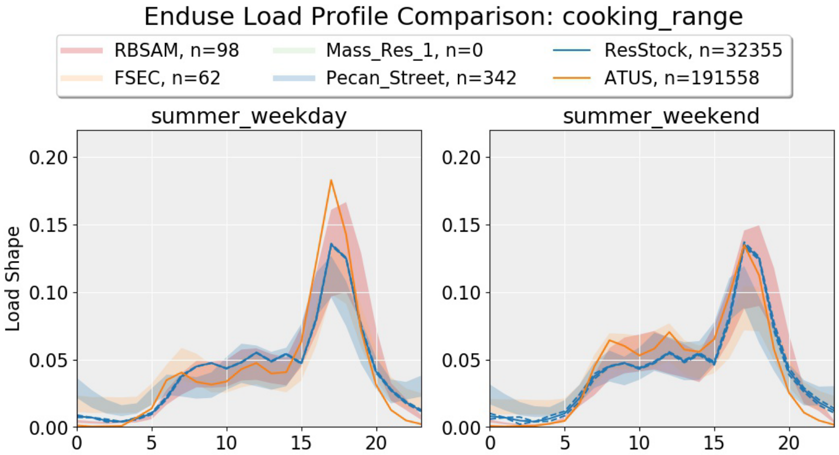
Question: Are residential end use patterns the same across regions?

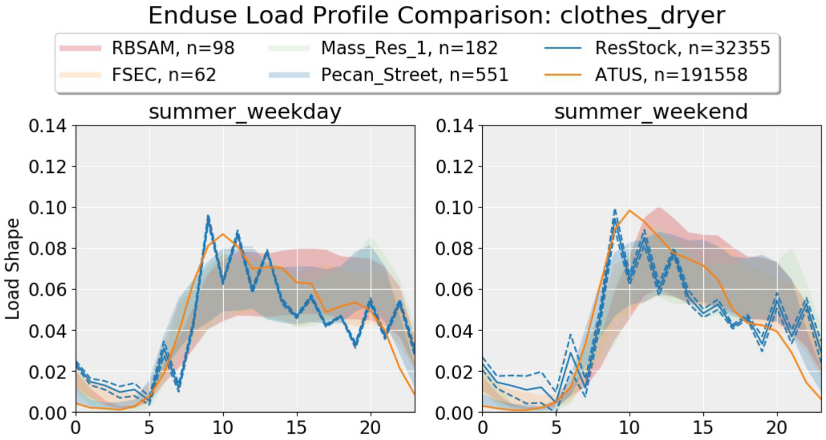
- Navigant Massachusetts Residential Baseline Study **(Mass Res 1)**
  - **356 sites,** metered between May 2017 and April 2018
  - **Massachusetts**, representative sample
- NEEA Residential Building Stock Assessment: Metering Study **(RBSAM)**
  - **101 homes,** metered from 2012-04-01 to 2014-07-31
  - **Pacific Northwest**, representative sample
- Florida Solar Energy Center - Phased Deep Retrofit Study **(FSEC)**
  - **56 homes,** metered from 2012 to 2016
  - Central Florida, biased sample
- Pecan Street Dataport **(Pecan Street)**
  - **998 homes,** metered between 2011 to 2014
  - **Texas** (97%), biased sample
- American Time Use Survey **(ATUS)**
  - **~55,000** respondents from 2013–2017 (one day of activities per respondent)
  - National, representative sample

Comparing ATUS to end-use datasets









New Residential Stochastic Occupant Behavior Model

Summary of Changes

Activity	2019 Status: Schedule Heterogeneity	2019 Status: Schedule Stochasticity	March 2020 Status: Schedule Heterogeneity	March 2020 Status: Schedule Stochasticity	Type: Occupants/ Household	Data sources: Start time	Data sources: Duration	Data sources: Magnitude (Power, Flow)
Occupant (heat gain)	No	No	Yes	Yes	Occupants	ATUS	ATUS	ATUS
Sinks HW	Yes*	Yes*	Yes	Yes	Household	DHWESG	DHWESG	DHWESG
Showers/Baths HW	Yes*	Yes*	Yes	Yes	Occupants	ATUS	DHWESG	DHWESG
Dishwasher HW	Yes*	Yes*	Yes	Yes	Occupants	ATUS	ATUS	DHWESG
Dishwasher kW	Yes*	Yes*	Yes	Yes	Occupants	ATUS	ATUS	End-use datasets
Clothes Washer HW	Yes*	Yes*	Yes	Yes	Occupants	ATUS	End-use datasets	DHWESG
Clothes Washer kW	Yes*	Yes*	Yes	Yes	Occupants	ATUS	DHWESG	End-use datasets
Clothes Dryer kW	Yes*	Yes*	Yes	Yes	Occupants	ATUS	End-use datasets	End-use datasets
Cooking Range	No	No	Yes	Yes	Occupants	ATUS	ATUS	End-use datasets
Misc. Electric Loads	No	No	Yes	Yes*	Household	Modify avg. schedule based on occupancy		
Lighting	No	No	Yes	Yes*	Household	Modify avg. schedule based on occupancy		
Thermostat setpoints	No	No	Yes	No	Household	RECS, ecobee		
Bath exhaust fan	No	No	Yes	No	Household	Modify schedule based on occupancy		
Kitchen exhaust fan	No	No	Yes	No	Household	Modify schedule based on occupancy		

* = Some degree of heterogeneity or stochasticity, but could be improved

ATUS = American Time Use Survey

DHWESG = NREL Domestic Hot Water Event Schedule Generator (based on data from the American Water Works Association)

End-use datasets = Pecan St., RBSAM, FSEC, etc.

1 home

Typical week

Time / Hour of Time

Variable	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday

Occupancy now changes day to day

Plug loads and lighting are lower when occupants are away or sleeping

Previously, cooking range was identical day-to-day

1000 homes

Typical week

10-minute resolution

Time / HourMinute

Variable	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday

Previously, using subhourly resolution exacerbated spikiness dramatically, due to insufficient diversity

Questions?

www.nrel.gov

https://www.nrel.gov/buildings/end-use-load-profiles.html

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

End-use Load Profiles for the U.S. Building Stock

Technical Advisory Group Meeting #10
April 22, 2021

Natalie Mims Frick, LBNL

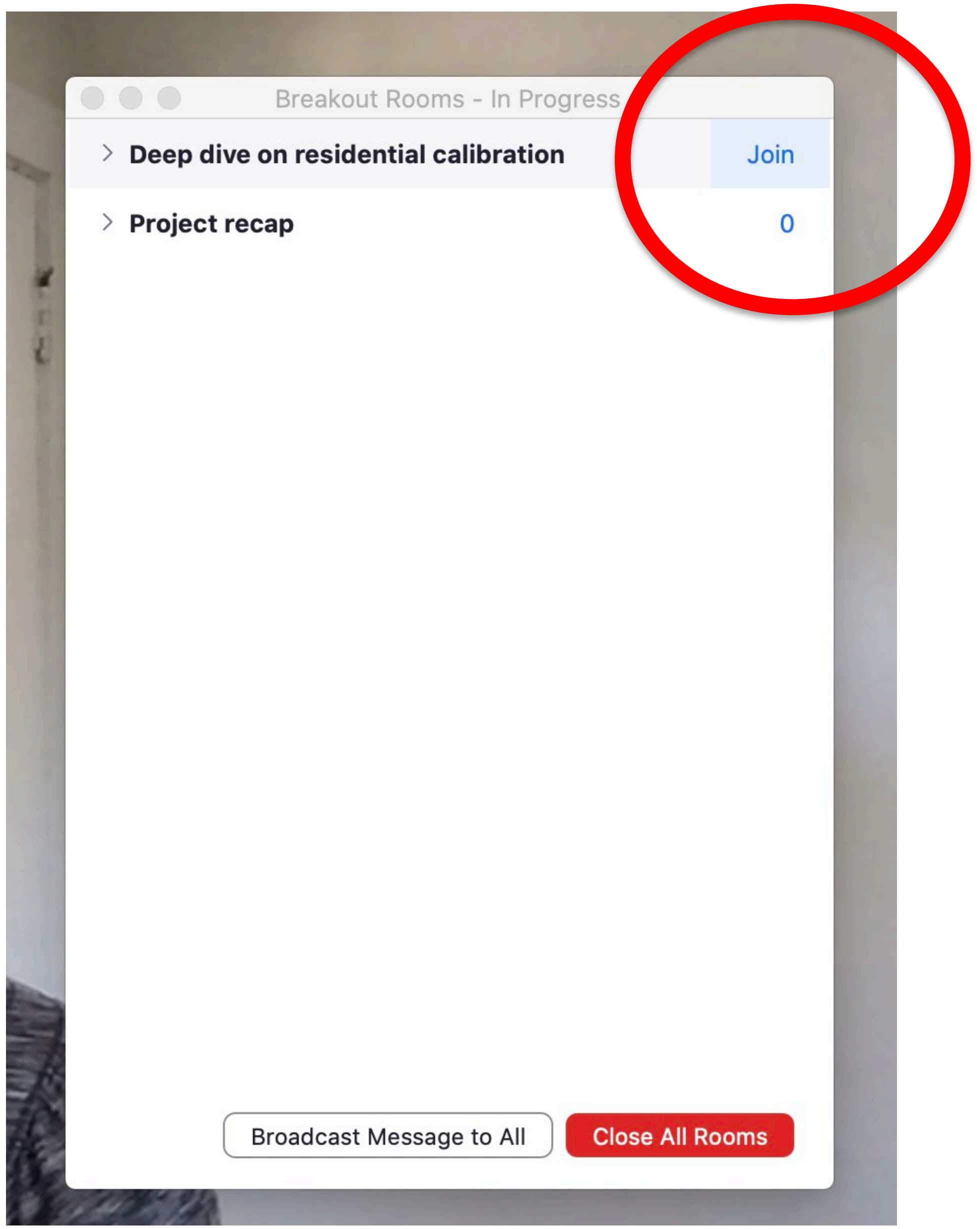
Logistics

- We are recording the webinar and breakout groups.
- Because of the large number of participants on the phone, please keep yourself muted during presentations.
- Please use the chat box to send us clarifying questions during presentations. You can chat or unmute yourself to ask a question during our designated discussion time.
- Links to the slides are in the chat box.

Today's agenda

	Mountain Time
Welcome	10:00 - 10:05
Data publication plan overview	10:05 - 10:25
Commercial calibration update	10:25 - 11:10
Breakout Room 1: Deep dive on commercial calibration Breakout Room 2: Electric vehicle infrastructure projection and charging load profile tool	11:10 - 11:50
Plenary 3 - What's next	11:50 - 12:25
Wrap up	12:25 -12:30

Selecting your breakout room



Room 1: *Deep dive on commercial calibration*. In this breakout session we will answer questions that members have on our commercial calibration. We can discuss questions pertaining to plenary presentation, past calibration results or other aspects of our commercial calibration process.

Room 2: *Electric vehicle infrastructure projection and charging load profile tool*. NREL researcher Eric Wood will presention [EVI-Pro Lite](), which is a tool that provides a simple way to estimate how much electric vehicle charging a state or city might need and how the mix of vehicle types and charging infrastructure types affects the charging load profile.

Breakout rooms will be recorded.

What's next?

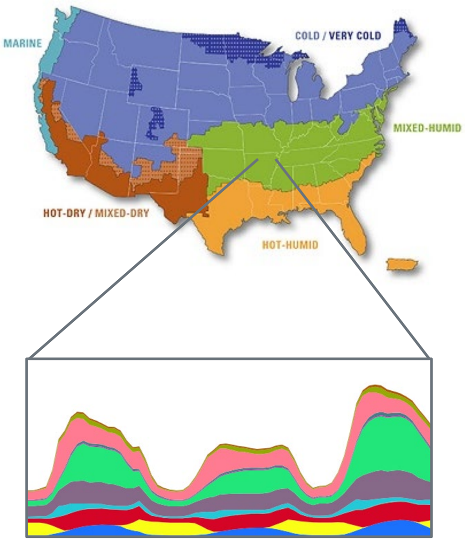
- What additional resources or effort is of most interest to you or your organization?
- What additional data or functionality would be most useful for our *residential* end use load shapes?
- What additional data or functionality would be most useful for our *commercial* end use load shapes?
- What additional model functionality would be useful?
- What topics do you hope we will cover in our final two TAG meetings?

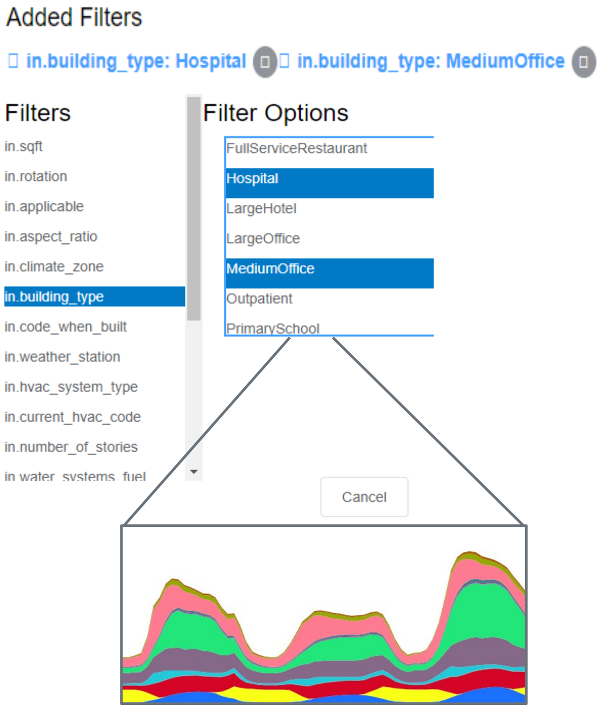
EULP Data Publication

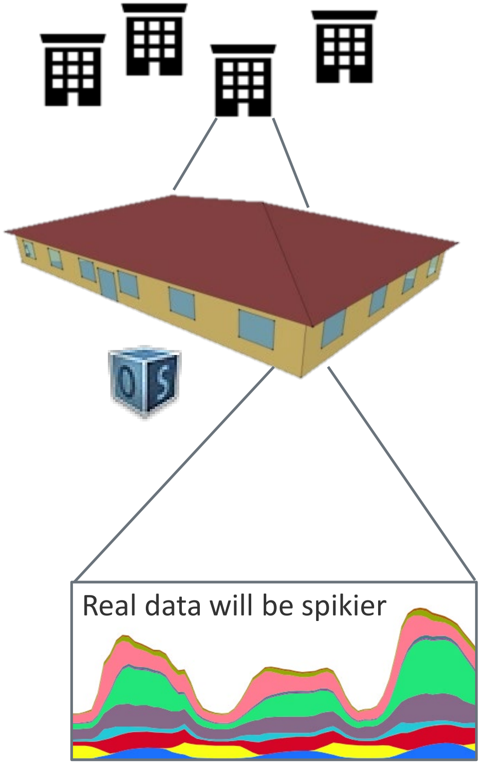
Andrew Parker
April 22, 2021

Same Data, Multiple Scales

Aggregates — Web Viewer — Individual Buildings





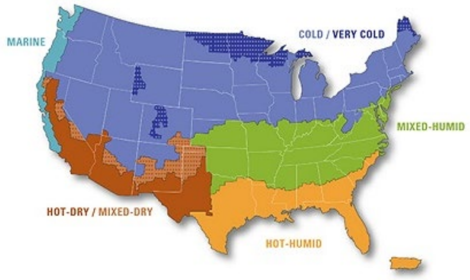


Pre-aggregated Load Profiles

Aggregates | Web Viewer | Individual Buildings

Pre-aggregated EULPs by building type for:

- U.S. States (contiguous)
- ASHRAE Climate Zones
- DOE Building America Climate Zones
- Electric System ISOs
- U.S. Census Public Use Microdata Area*
- U.S. Counties



Format:

- CSV files (for Excel, etc. ease of use)

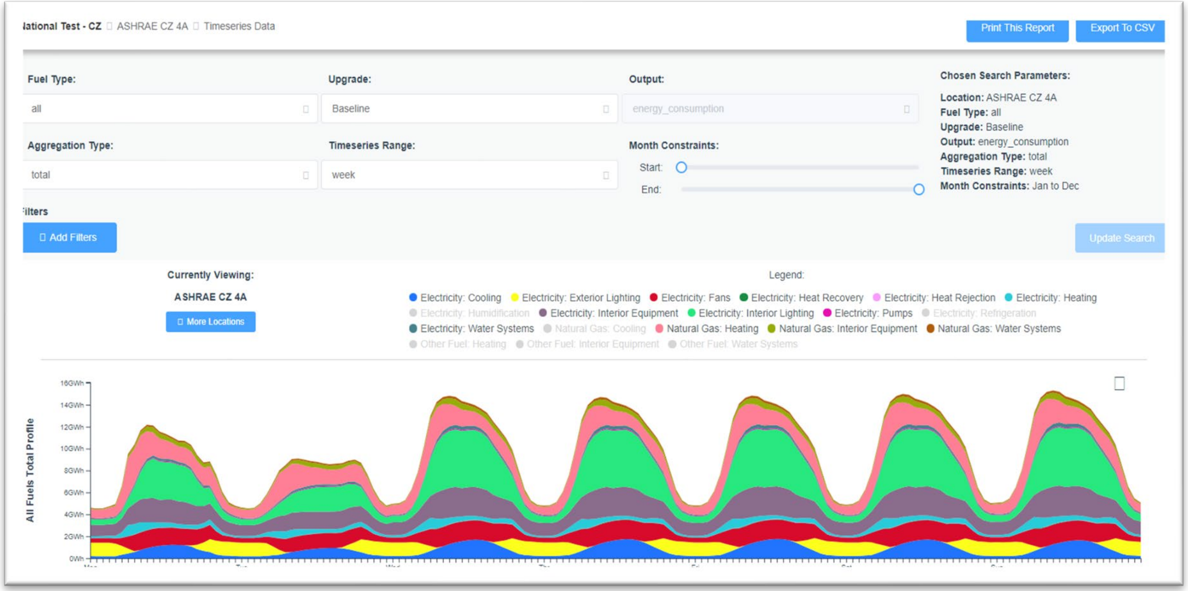
Additional Data:

- Count of models included per aggregation
- List of model IDs per aggregation
- Model characteristics by ID
- Timeseries mean, stdev, and range

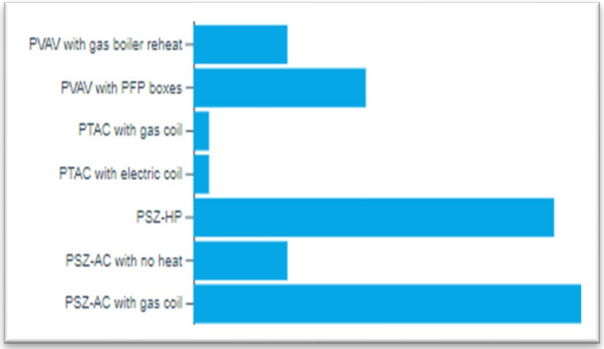
*PUMA is an area with ~200k people; ~2,400 in U.S.

VizStock Web Interface

Aggregates | Web Viewer | Individual Buildings



- View End Use Load Profiles
- View distributions of building characteristics
- Filter by building characteristic
- Filter by geography
- Select time window
- Download CSV of results



Individual Buildings – Load Profiles & Models

Aggregates | Web Viewer | Individual Buildings

Individual Building End Use Load Profiles

- ~450,000 residential
- ~350,000 commercial
- Full dataset will be 10's of terabytes
- Plan to include high-level instructions for loading this dataset using one cloud-based big-data analysis tool

Format:

- Folders with a series of Apache parquet* files
  - Likely 1 file per building, with IDs in names
- In Amazon S3 bucket or similar

Additional Data:

- Model characteristics by ID
- Model in OpenStudio (.osm) format

*https://parquet.apache.org/

2 Sets of Weather Data = 2 Sets of EULPs

Typical Meteorological Year (TMY3)

- Widely accepted/expected by utilities, regulators, etc.
- Weather is not coordinated across regions

	Weather Data from Year	
Month	Denver, CO	Boulder, CO
January	1995	1987
February	1994	1990
March	1991	1981
April	1999	1986

2 locations 40 miles apart use data from different years for the same month

Actual Meteorological Year (AMY)

- Using 2018 NOAA data

Format:

- CSV timeseries data for each location used
  - Dry bulb temperature
  - Relative humidity
  - Solar direct normal irradiation
  - Solar diffuse horizontal irradiation
  - Wind speed
  - Building characteristics
- Location used for each Model

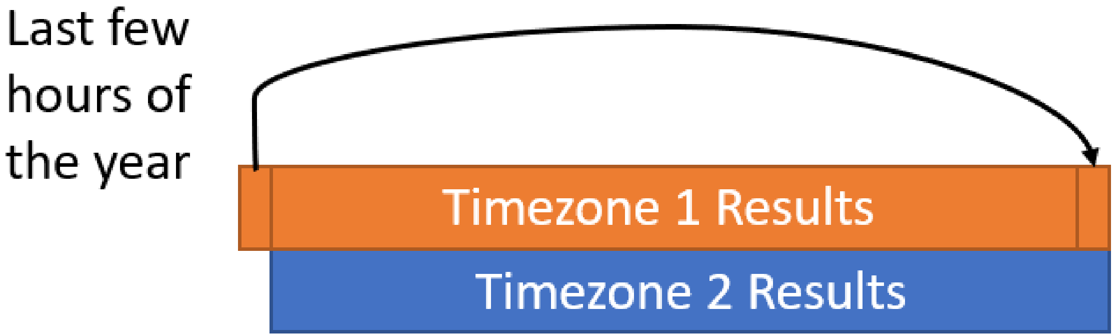
Time Stamps & Time Zones

Time Zones:

- **Data will be provided in UTC**

Time Stamps:

- **Wrap data from first few hours of year back to the end**
- **Creates a single, aligned 1 year worth of data**



Questions & Discussion

Residential Building Types & End Uses

Residential Building Types	Residential End Uses
Single-Family Detached	Heating
Single-Family Attached	Cooling
Multifamily 2–4 Units	Furnace/AC fan
Multifamily 5+ Units (1-3 stories)	Boiler pumps
Multifamily 5+ Units (4-7 stories)	Vent. fans
Multifamily 5+ Units (8+ stories)	Water heating
	Interior Lights
	Exterior Lights
	Misc. plug loads
	Refrigerator
	Clothes washer
	Clothes dryer
	Dishwasher
	Cooking Range

Commercial Building Types & End Uses

Commercial Building Types	Commercial End Uses
Small Office	Heating
Medium Office	Cooling
Large Office	Interior Lighting
Stand-alone Retail	Exterior Lighting
Strip Mall	Interior Equipment
Primary School	Exterior Equipment
Secondary School	Fans
Outpatient Healthcare	Pumps
Hospital	Heat Rejection
Small Hotel	Humidification
Large Hotel	Heat Recovery
Warehouse (non-refrigerated)	Water Systems
Quick Service Restaurant	Refrigeration
Full Service Restaurant	

Residential Building Characteristics

Residential Model Characteristics	(continued)	(continued)
ahs_region	heating_fuel	location_latitude
applicable	heating_setpoint	location_longitude
ashrae_iecc_climate_zone_2004	heating_setpoint_has_offset	location_region
bathroom_spot_vent_hour	heating_setpoint_offset_magnitude	location_state
bedrooms	heating_setpoint_offset_period	mechanical_ventilation
building_america_climate_zone	holiday_lighting	misc_extra_refrigerator
ceiling_fan	hot_water_distribution	misc_freezer
census_division	hot_water_fixtures	misc_gas_fireplace
census_region	hvac_system_cooling	misc_gas_grill
climate_zone_ba	hvac_system_cooling_type	misc_gas_lighting
climate_zone_iecc	hvac_system_heat_pump	misc_hot_tub_spa
clothes_dryer	hvac_system_heating_electricity	misc_pool
clothes_washer	hvac_system_heating_fuel_oil	misc_pool_heater
clothes_washer_presence	hvac_system_heating_natural_gas	misc_pool_pump
cooking_range	hvac_system_heating_none	misc_pool_schedule
cooking_range_schedule	hvac_system_heating_other_fuel	misc_well_pump
cooling_setpoint	hvac_system_heating_propane	natural_ventilation
cooling_setpoint_has_offset	hvac_system_is_heat_pump	neighbors
cooling_setpoint_offset_magnitude	hvac_system_is_shared	occupants
cooling_setpoint_offset_period	hvac_system_shared_electricity	orientation
corridor	hvac_system_shared_fuel_oil	overhangs
county	hvac_system_shared_natural_gas	plug_loads
days_shifted	hvac_system_shared_none	plug_loads_schedule
dehumidifier	hvac_system_shared_other_fuel	puma
dishwasher	hvac_system_shared_propane	pv
door_area	infiltration	radiant_barrier
doors	insulation_crawlspace	range_spot_vent_hour
ducts	insulation_finished_basement	refrigeration_schedule
eaves	insulation_finished_roof	refrigerator
electric_vehicle	insulation_interzonal_floor	roof_material_finished_roof
geometry_building_number_units_hl	insulation_pier_beam	roof_material_unfinished_attic
geometry_building_number_units_mf	insulation_slab	sample_weight
geometry_building_number_units_sfa	insulation_unfinished_attic	solar_hot_water
geometry_building_type_acs	insulation_unfinished_basement	state
geometry_building_type_recs	insulation_wall	units_modeled
geometry_floor_area	interior_shading	units_represented
geometry_floor_area_bin	iso_rto_region	usage_level
geometry_foundation_type	lighting	vintage
geometry_garage	lighting_interior_use	vintage_acs
geometry_perimeter_footprint_ratio	lighting_other_use	water_heater
geometry_stories	location	window_areas
geometry_wall_type	location_city	windows

Commercial Building Characteristics

Commercial Model Characteristics	**(continued)**
building_type	cooling_source_fuel
climate_zone	heating_source_fuel
weather_file_name	hvac_delivery_type
rentable_area	service_water_heating_source_fuel
number_stories	kitchen_makeup
aspect_ratio	exterior_lighting_zone
total_bldg_floor_area	onsite_parking_fraction
bottom_story_ground_exposed_floor	energy_code_when_built
building_height_relative_to_neighbors	energy_code_when_envelope_last_updated
building_rotation	energy_code_when_exterior_lighting_last_updated
floor_to_floor_height	energy_code_when_hvac_last_updated
party_wall_stories_west	party_wall_fraction
single_floor_area	party_wall_stories_east
story_multiplier	party_wall_stories_north
top_story_exterior_exposed_roof	party_wall_stories_south
window_to_wall_ratio	energy_code_when_interior_equipment_last_updated
hvac_system_type	energy_code_when_interior_lighting_last_updated
energy_code_when_service_water_heating_last_updated	
weekday_operation_start_time	
weekday_operation_duration	
weekend_operation_start_time	
weekend_operation_duration	

Commercial Calibration Update Region 2 & Overall Status

Andrew Parker
Matthew Dahlhausen
April 22, 2021

Commercial Calibration Team

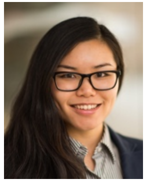
Dr. Rajendra Adhikari

Dr. Anthony Fontanini

Chris CaraDonna

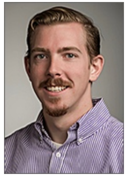
Dr. Matthew Dahlhausen

Amy LeBar



Dr. Lixi Liu

Dr. Janghyun Kim



Andrew Parker

Elaina Present

Calibration Progress

About 60% through the commercial calibration timeline

- Finished Region 1 of 4 (Ft. Collins) in Fall 2020
  - Paused commercial calibration while awaiting AMI data
- Finished Region 2 of 4 (Seattle, Portland) in February 2021 - today's focus
- Halfway through Region 3 of 4 (Cold/Very Cold) today
- Region 4 of 4 (Southeast) June-August 2021

Commercial AMI Data Challenges

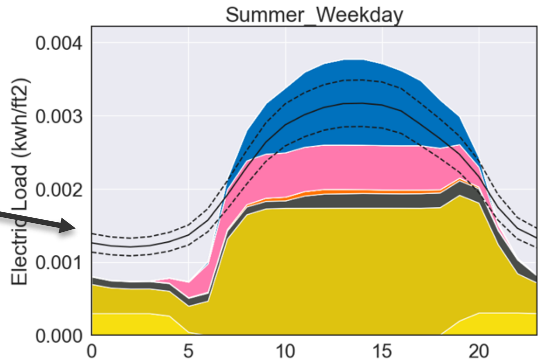
- ✓ Misclassification of buildings (outlier removal technique, see previous TAG presentation)
- ✓ Partially-occupied buildings (outlier removal)
- ✓ Knowingly/unknowingly missing large fraction of meters for a building (outlier removal)
- ✓ Missing some timesteps for some meters (new method, described in later slides)
- ? Knowingly missing a small fraction of the meters for a building
  - Reason may vary between utilities (meters not all AMI, meters defunct, oversight)
  - Current crude correction: assume equal area served by all meters, scale floor area
  - Investigating prevalence of this situation and impact of this correction now
- ✗ Unknowingly missing a small fraction of the meters for a building
  - EUI likely within 3x median, load shape still reasonable… undetectable error?

For utilities, fundamental unit of reporting one meter, not buildings or sqft

Commercial AMI Confidence

Current Situation **(all graphs in this slide deck)**

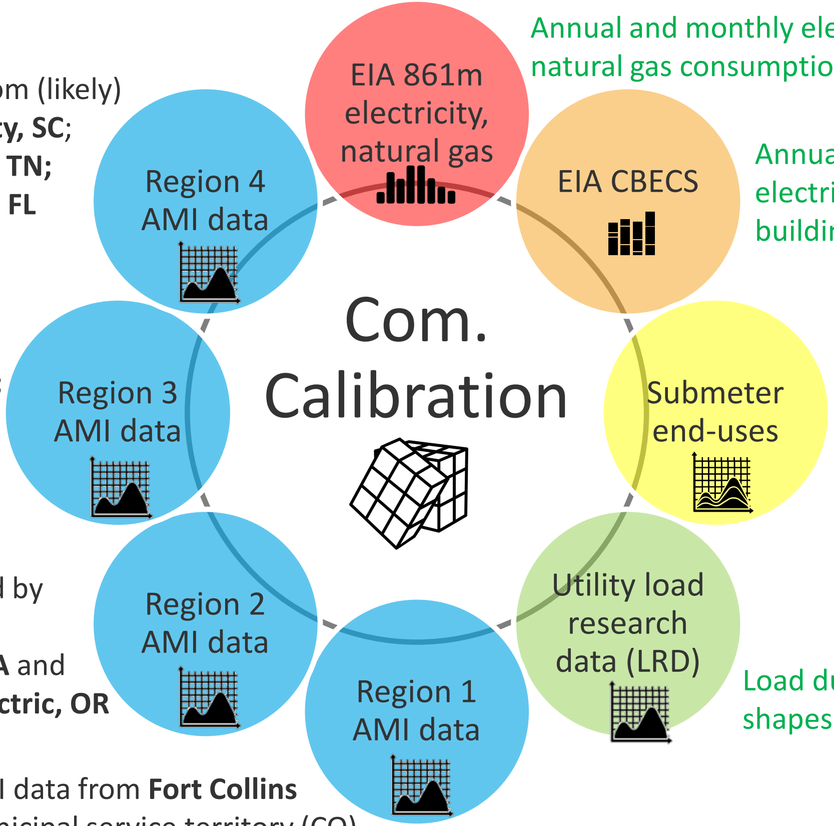
- Graphs show mean AMI (kWh/sqft per hr)
- Dashed lines show mean +/- 10%
- Overstates confidence in the mean of the AMI



Plan to Address:

1. Adjust AMI confidence bands based on sample size
   - Realistic depiction of confidence in AMI mean
   - Ranges likely large for building types and datasets with smaller sample sizes. Sometimes too large to inform model changes?
2. (Maybe) Focus on AMI for load shape comparison, use CBECS for load magnitude comparison
   - Upside: don't drive model changes with uncertain data
   - Downside: CBECS data from different year, less geographically condensed
3. Other? – discuss during breakout

Commercial Calibration Dimensions



Annual and monthly electricity and natural gas consumption by state, sector

Annual gas and electricity EUIs by building type

Sub-metered end-use load data (10 datasets)

Load duration curves and seasonal load shapes of ~16 utilities around U.S.

AMI data from (likely) **Horry County, SC**; **Chatanooga TN; Tallahassee, FL**

AMI data from **Vermont; Maine; Cherryland, MI**

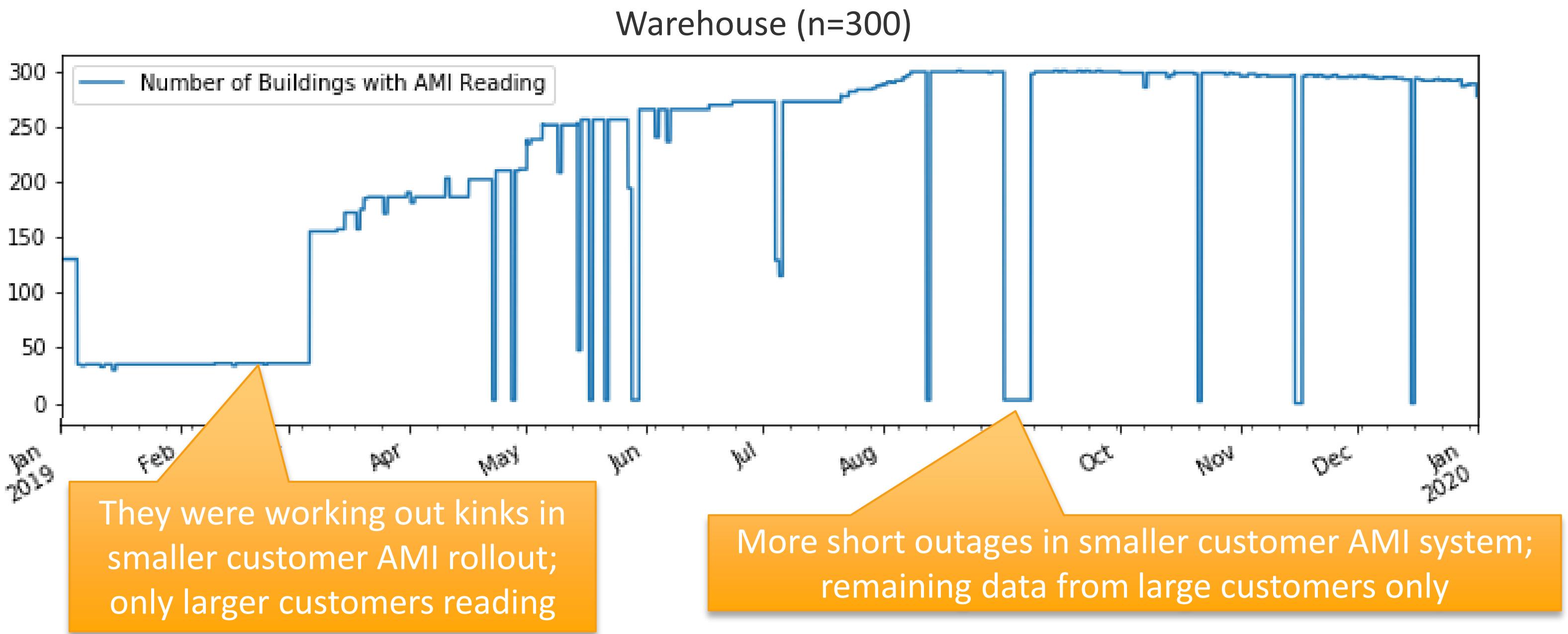
AMI data (aggregated by building type) from **Seattle City Light, WA** and **Portland General Electric, OR**

AMI data from **Fort Collins** municipal service territory (CO)

Addressing Gaps in AMI Data

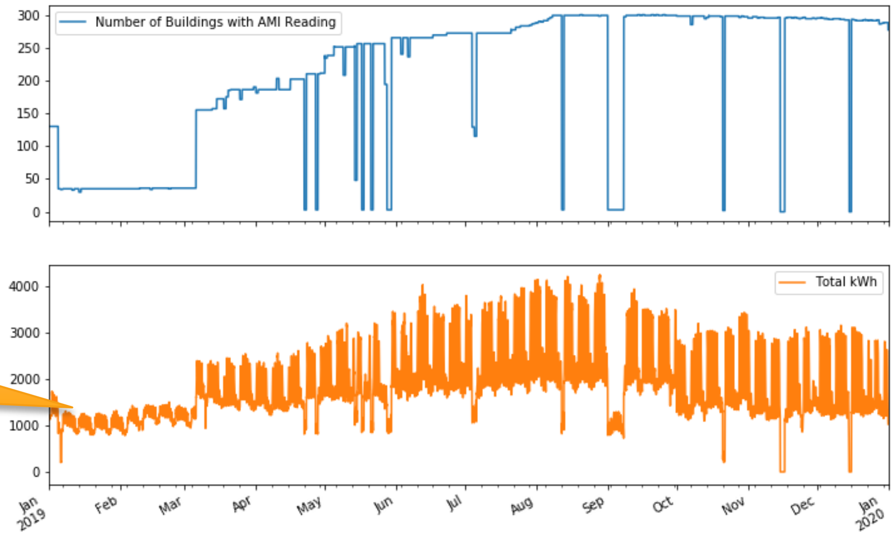
Seattle AMI Challenges

- Seattle has two separate AMI recording systems
  - One for smaller customers rolled out in 2018
  - One for larger customers rolled out earlier
- Many building types only have data from larger customers for some periods



Seattle AMI Challenges

Warehouse (n=300)



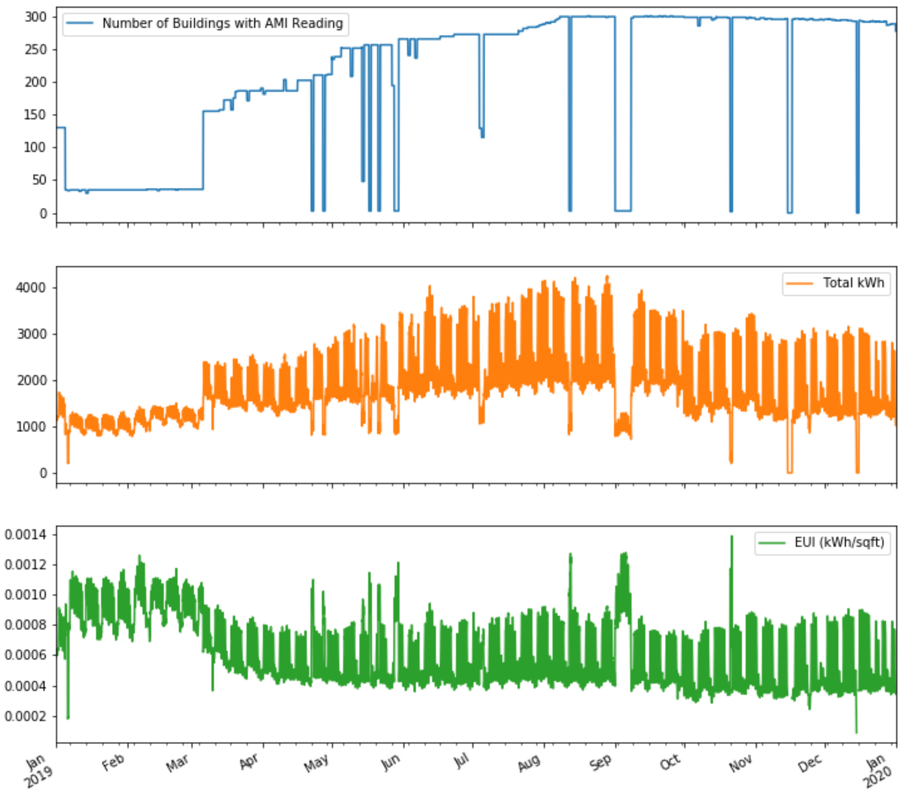
As expected, fewer buildings means less energy for those timesteps

Seattle AMI Challenges

The meters that remain on are in the larger-customer AMI system.

This skews the EUI toward those buildings (higher) during meter outages

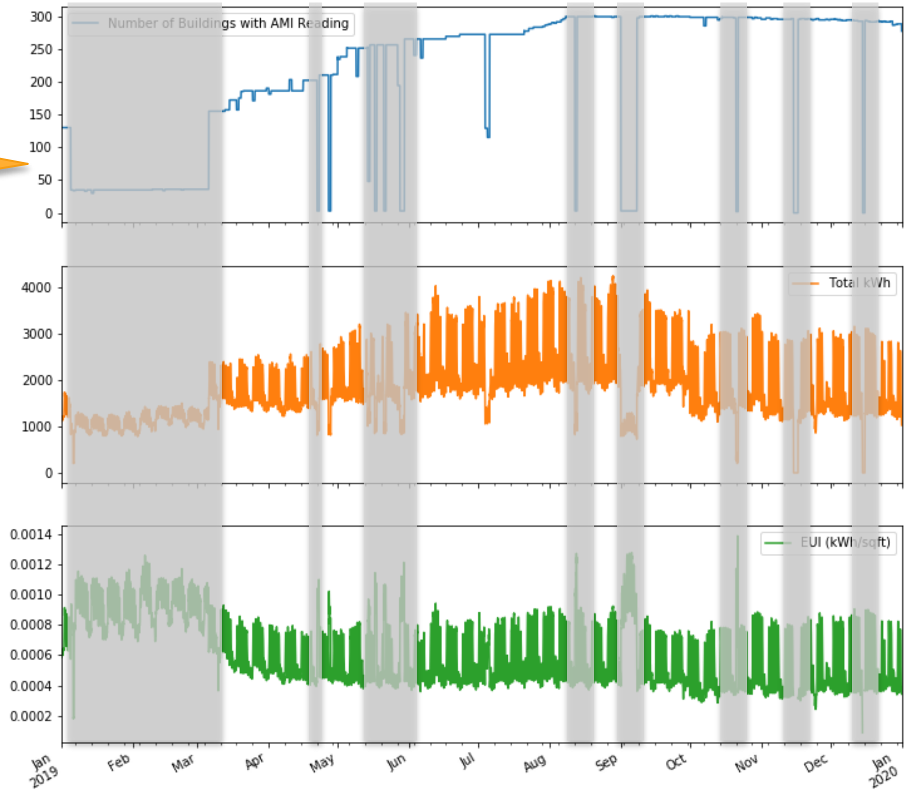
Warehouse (n=300)



Seattle AMI Solution

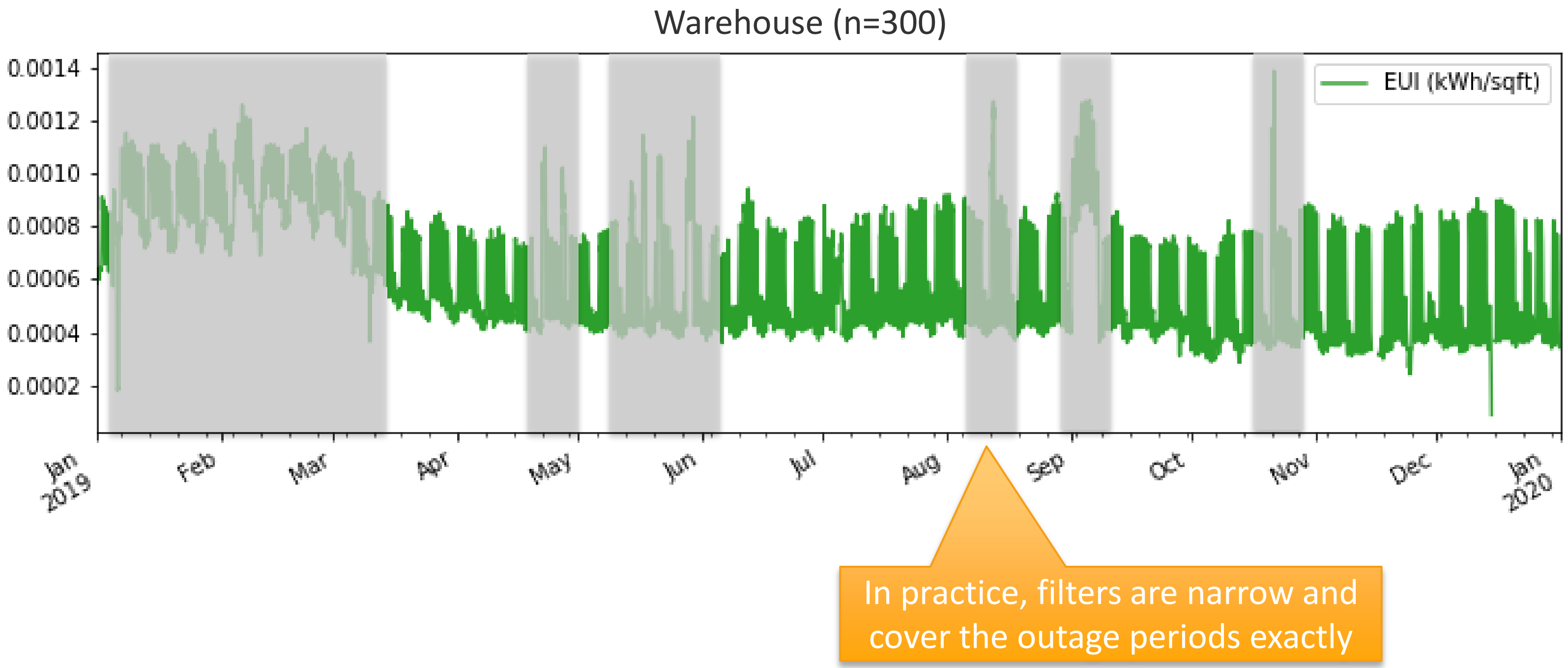
For calibration, drop data from timesteps where # buildings < 30%

Warehouse (n=300)



Seattle AMI Solution (Implemented)

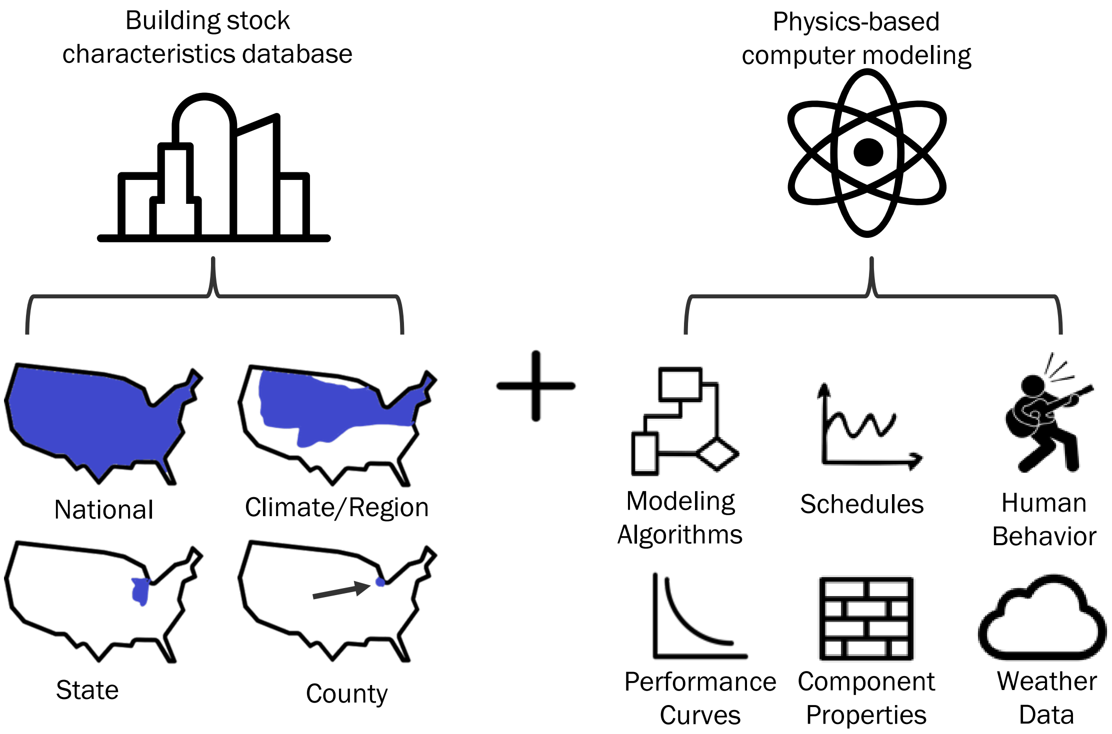
- For calibration, drop data from timesteps where # buildings < 30%
- Not all building type have same outage periods
- Not all building types show as noticeable EUI bias during outage periods



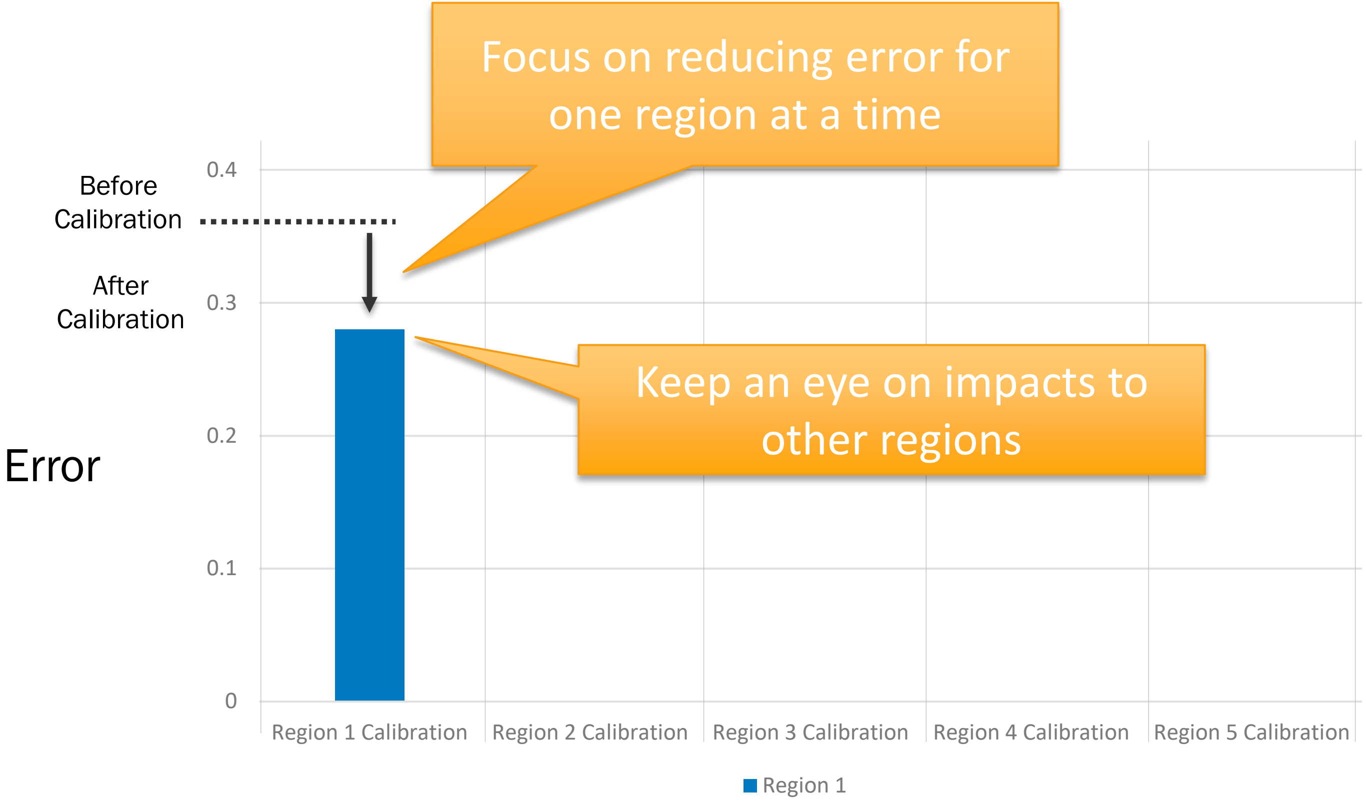
Calibration Strategy

Model Architecture

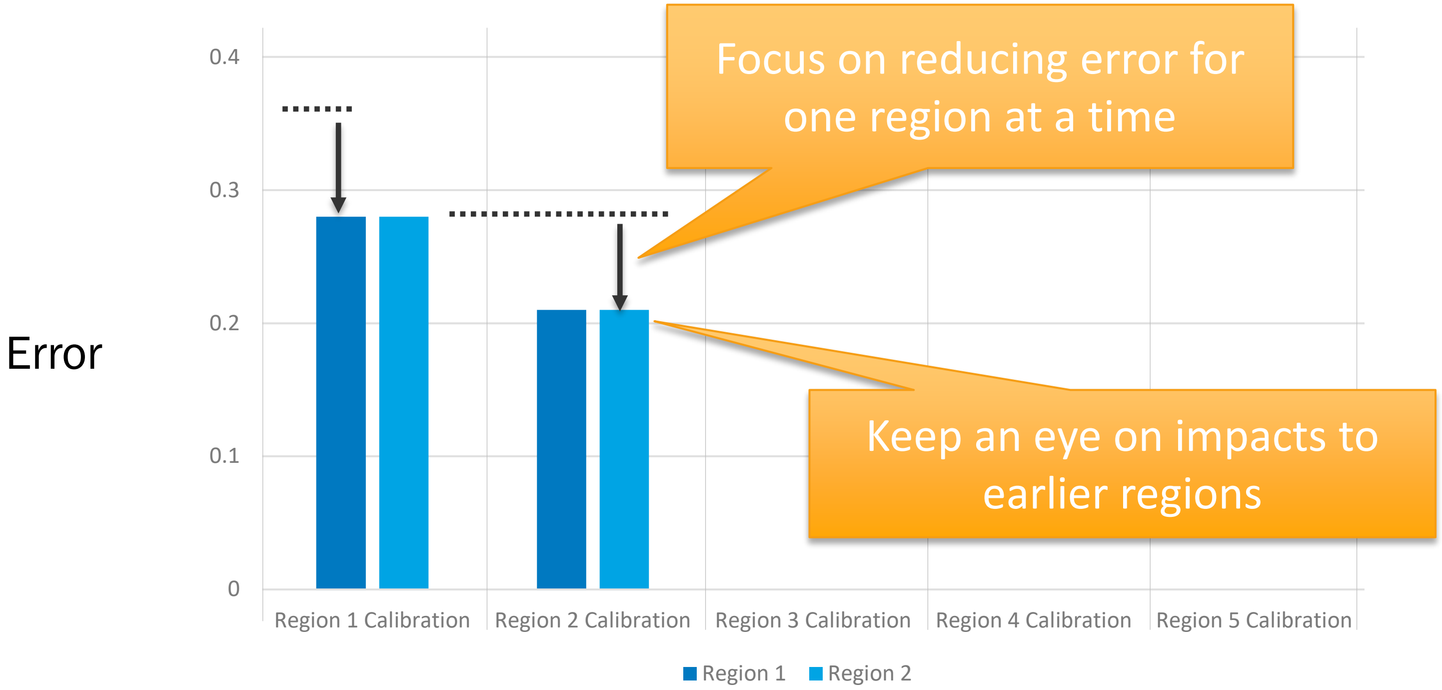
ComStock



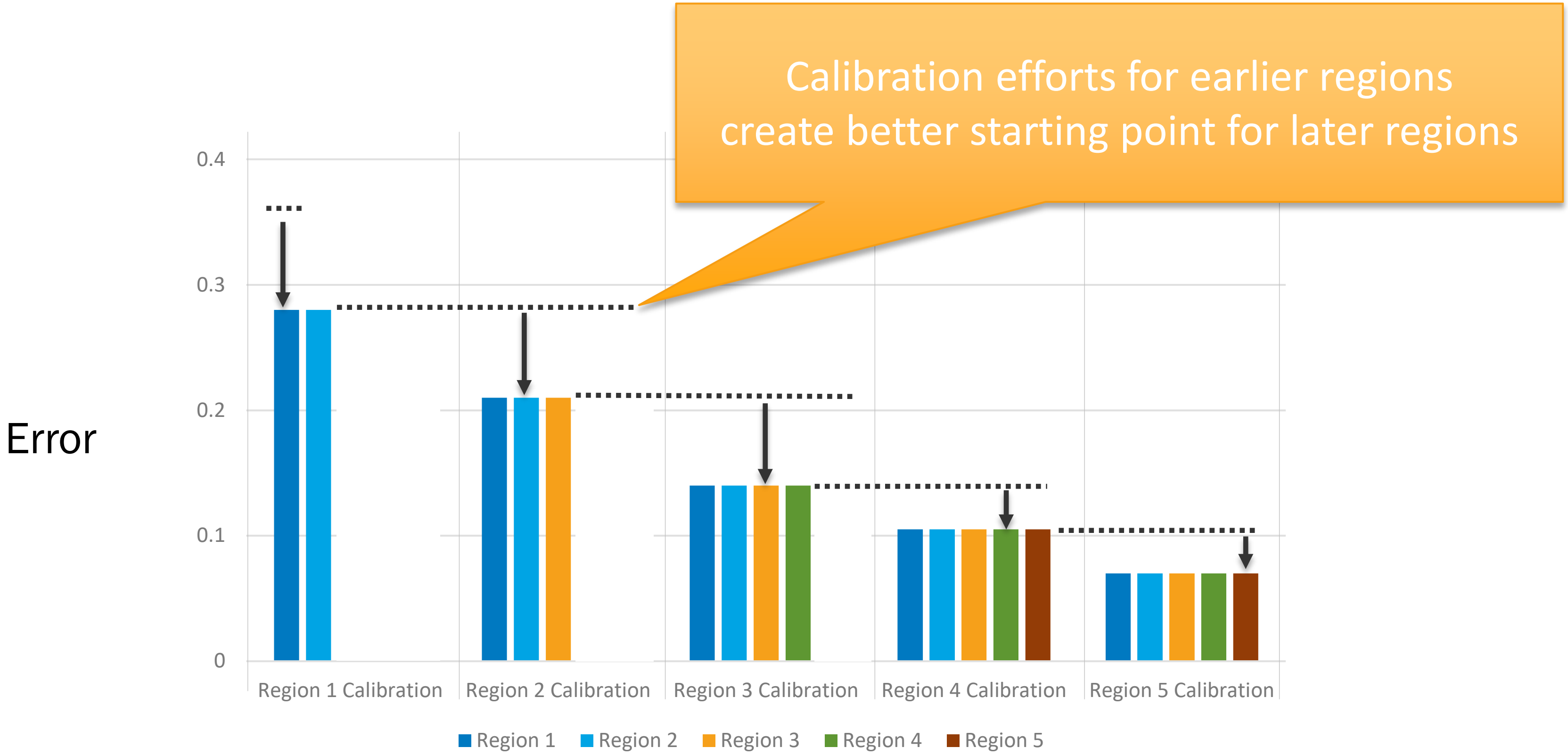
Calibration Process for One Region



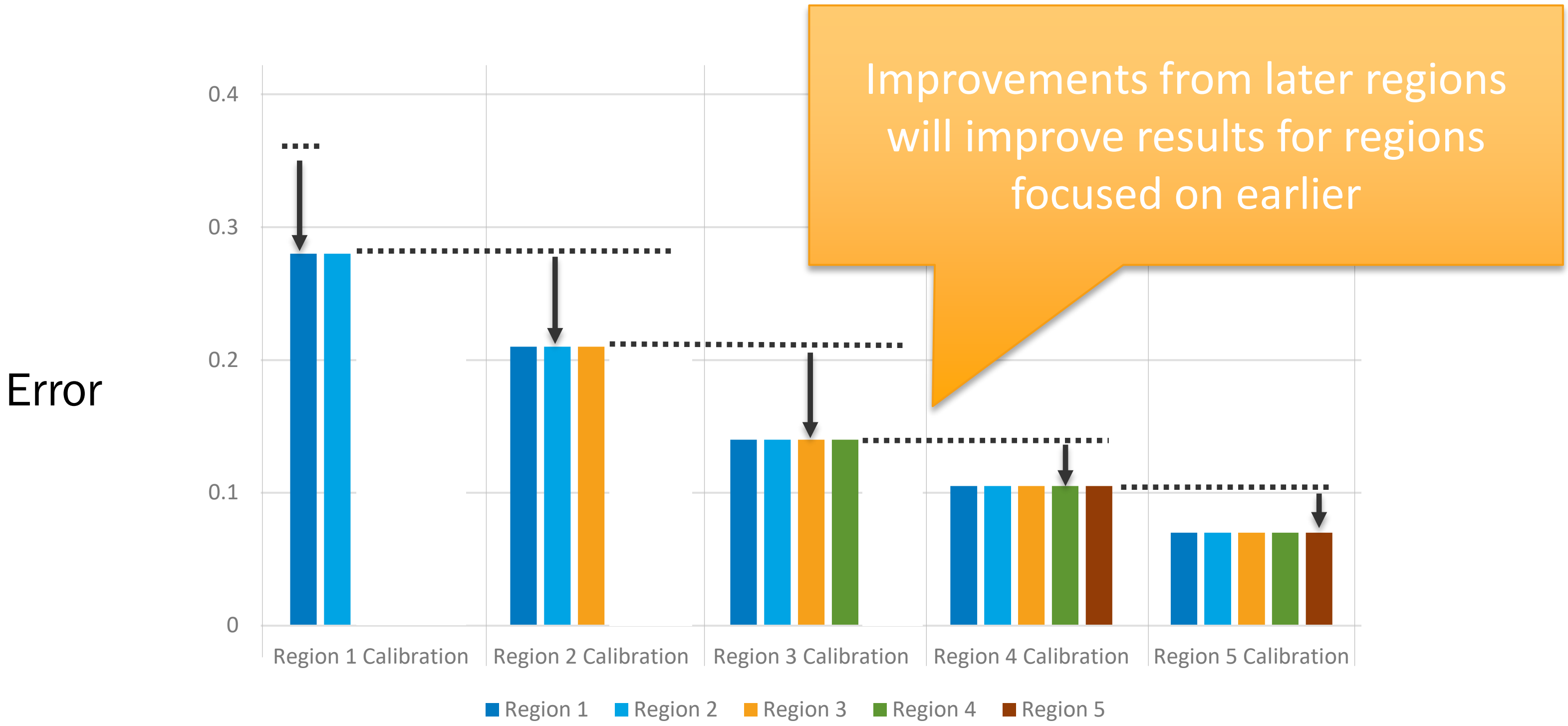
Calibration Process Over Time



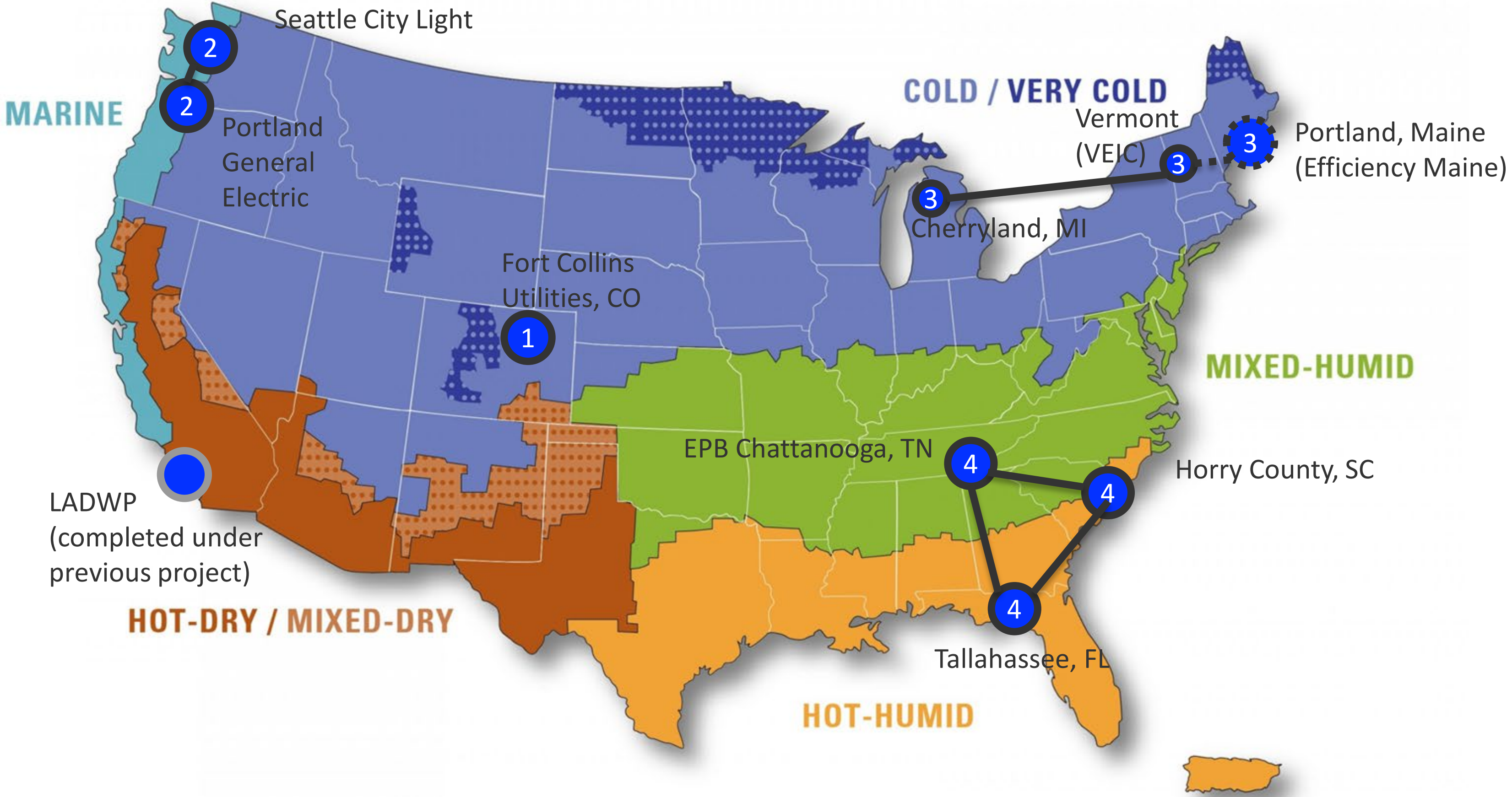
Calibration Process Over Time



Calibration Process Over Time

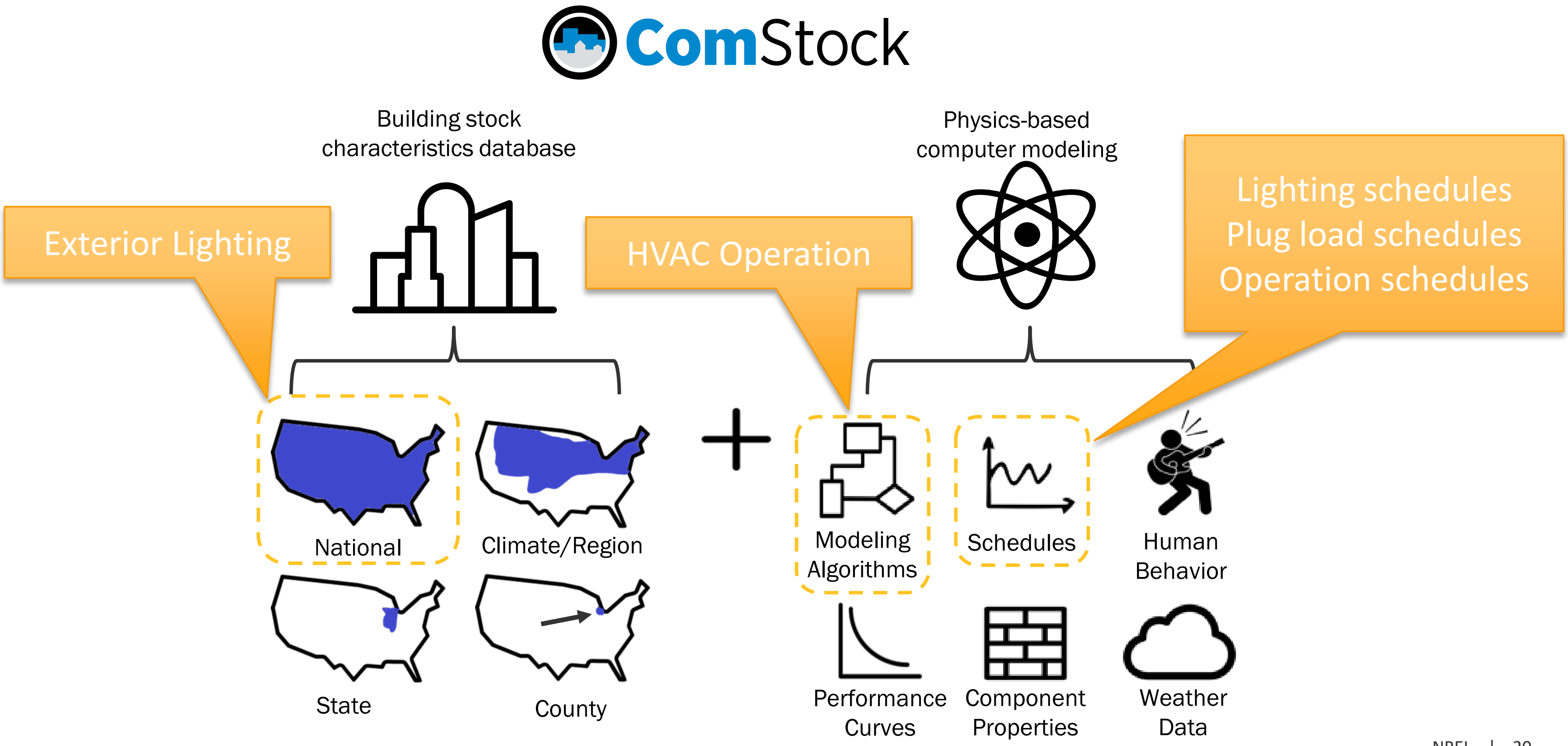


Summary of Commercial AMI Calibration Regions



Background colors are DOE Building America Climate Regions

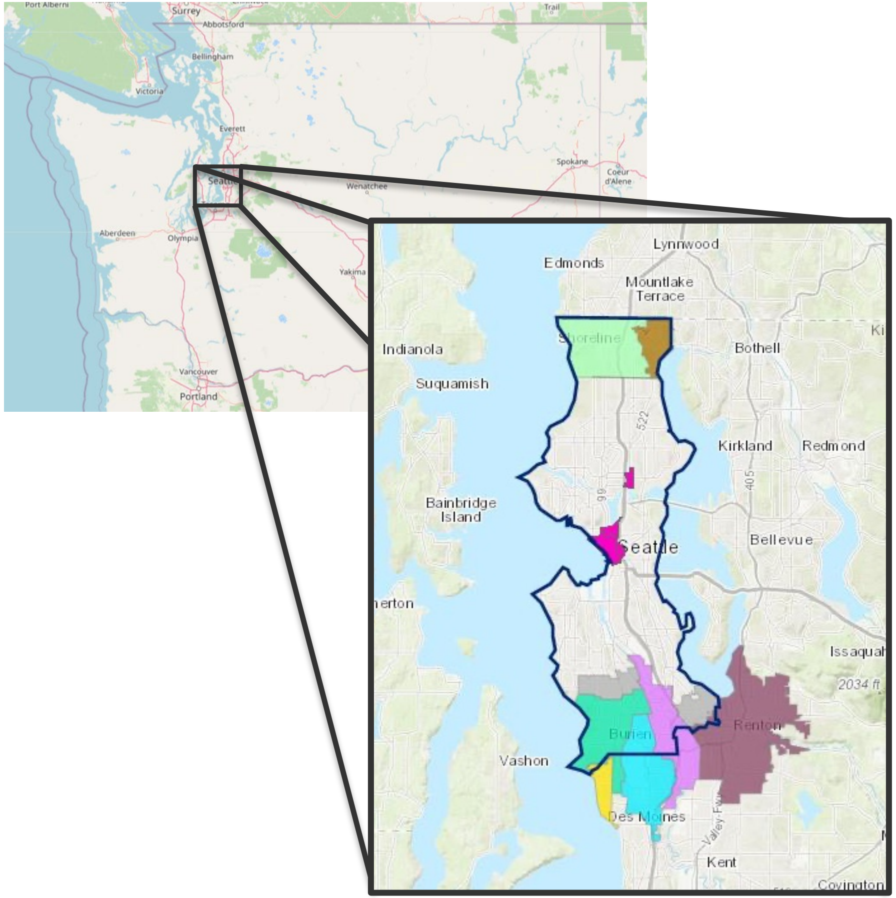
Region 2 Focus: Major Schedules



Region 2a – Seattle, WA

- Seattle, WA (pop. ~745k) plus parts of adjacent suburbs
- Municipal utility
- AMI data from 2019 (aggregated by building type)

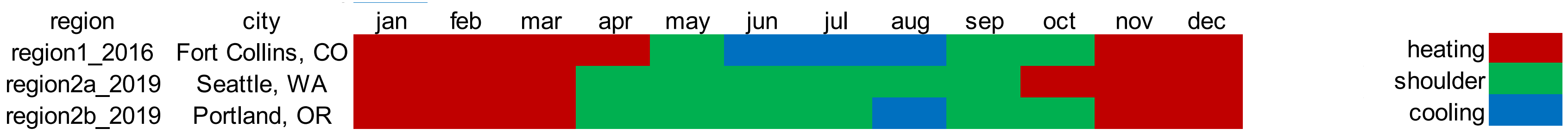
building_type	count
full_service_restaurant	167
hospital	12
large_hotel	39
large_office	137
medium_office	109
outpatient	162
primary_school	43
quick_service_restaurant	40
retail	485
small_hotel	25
small_office	693
strip_mall	941
warehouse	633



Region 2a – Seattle, WA – No Summer

- Assign “season” to each month to enable comparison across regions
  - Based on average daily temperatures in each month for weather used
    - Winter/heating < 55°
    - > 55° Shoulder < 70°F
    - Summer/cooling > 70°F
  - May not match what residents think of as seasons
  - Therefore, “Summer” is missing in the Seattle graphs

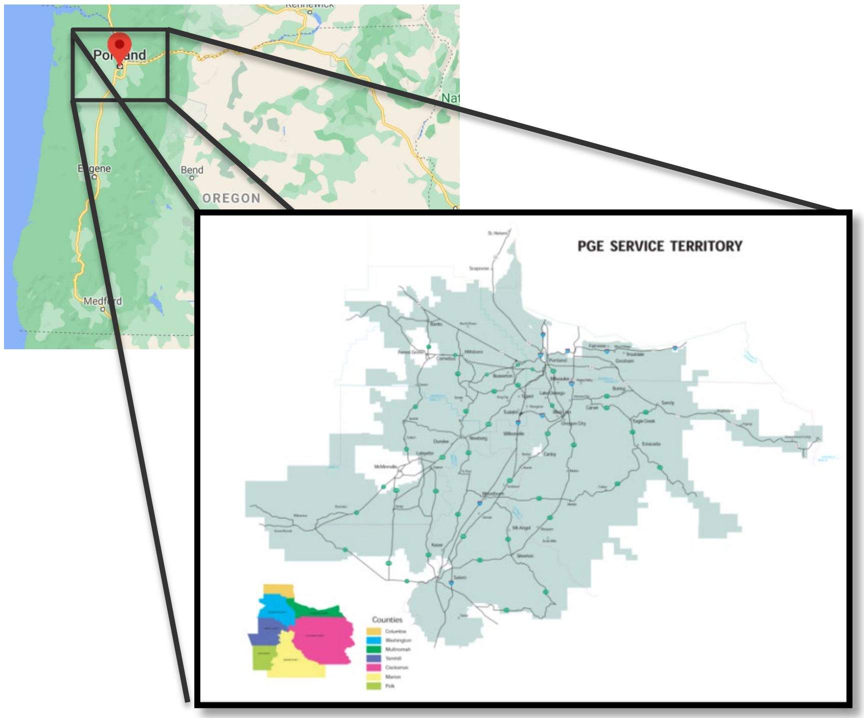
Monthly Season Definitions



Region 2b – Portland, OR

- Portland (Portland General Electric)
- Publicly-traded Utility
- AMI data from 2019

building_type	count
full_service_restaurant	391
hospital	13
large_hotel	92
medium_office	13
outpatient	530
primary_school	105
quick_service_restaurant	119
retail	1,193
small_hotel	59
small_office	303
strip_mall	1,215
warehouse	2,511



List of updates

Misclassification/Outlier Detection

- Comparison of approaches w/ large Xcel dataset (presented in detail at TAG meeting)

New validation comparisons

- AMI data from Seattle City Light (aggregated by building type)
- AMI data from Portland General Electric

New capabilities

- None

Baseload updates

- Interior lighting schedule magnitude variability
- Plug load schedule magnitude variability
- Exterior lighting power density
- Warehouse operation schedules (lighting, plug load, occupancy)

HVAC updates

- Off cycle controls for packaged single-zone systems

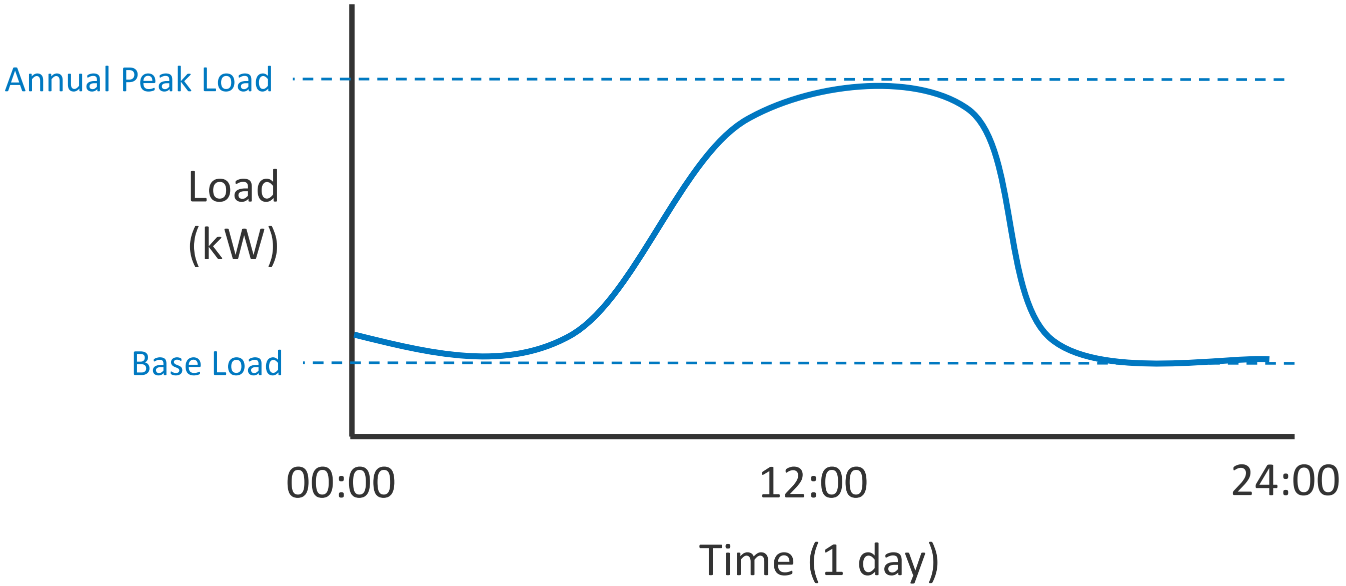
Baseload Updates

Update: Variability in Lighting & Plug-load Schedules

Task	Affected Building Type	Considerations
Interior lighting schedule magnitude variability	retail, food service, school, office	• Magnitude variability (base-to-peak ratio) in schedules are captured from end-use (lighting & plug load) data. • Standardized workflow added in ComStock to incorporate variability captured from end-use data. • Lighting/Plug-load schedule variability improved.
Plug load schedule magnitude variability		

Base-to-Peak Ratio

- Base-to-Peak Ratio (BPR) = Base Load / Annual Peak Load
- A way to describe to what degree loads are reduced at night



Base-to-Peak Ratio

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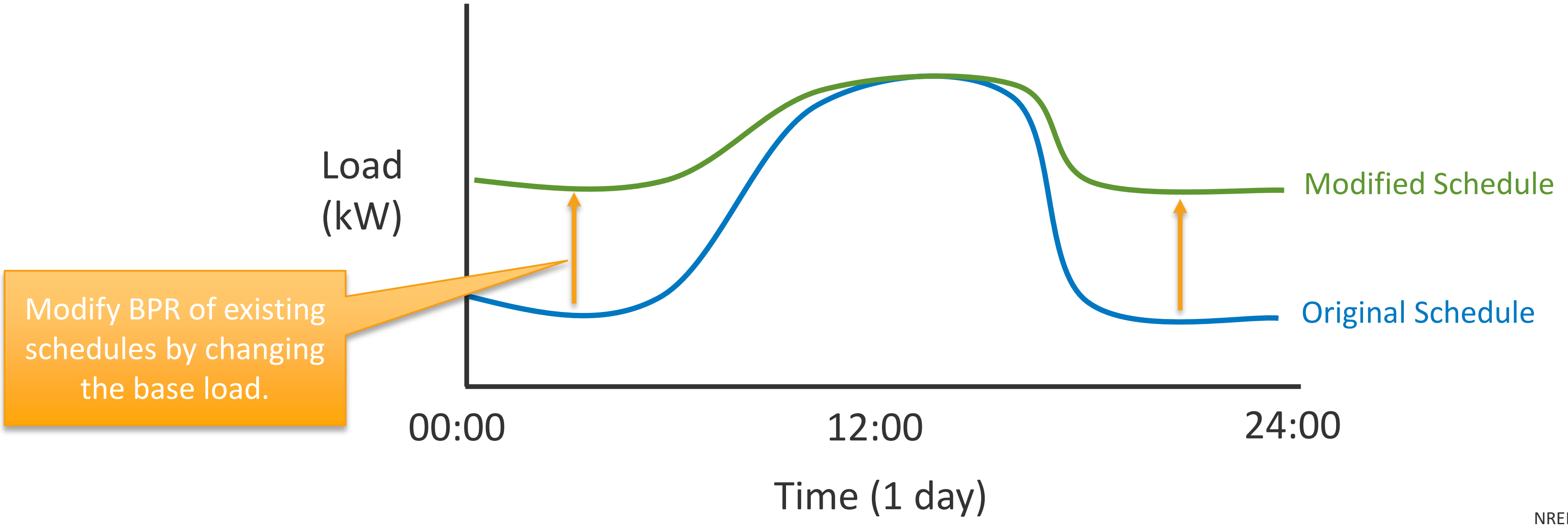


Update: Lighting & Plug-load Base-to-Peak Variability

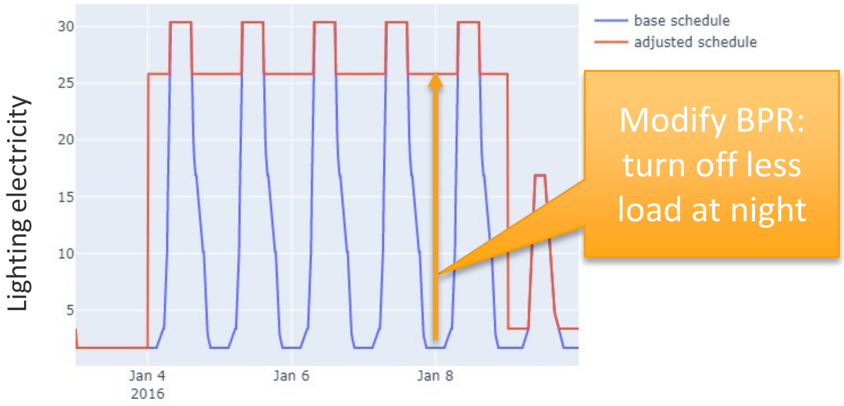
Creating base-to-peak ratio (BPR) distributions

- Lighting and plug load schedules were pulled from two commercial end use datasets that we procured.
- A data clustering analysis was performed to group the schedules based on various BPR distributions resulting in 6 different cluster types covering all considered building types.
- Distributions were calculated based on these clusters and implemented in the ComStock sampling approach as *wkdy_bpr* and *wknd_bpr* values.

Measure implementation

- The measure sets the base period of interior lighting and equipment (plug load) schedules within a model to a BPR.
- Two arguments: *wkdy_bpr* modifies weekday schedules, and *wknd_bpr* modifies weekend schedules.

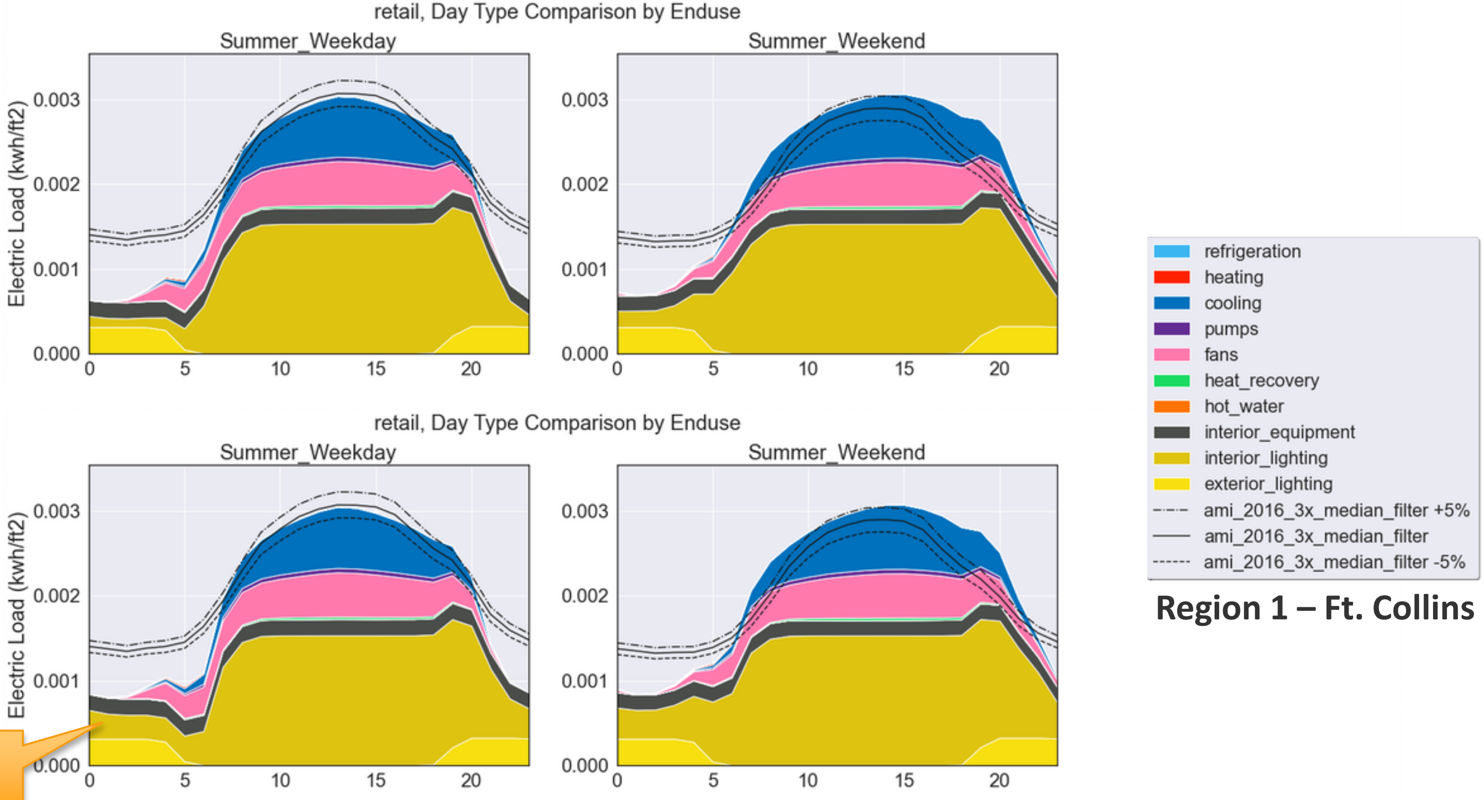
Example measure results



Impact: Lighting Base-to-Peak Variability

Before

After



Higher base load

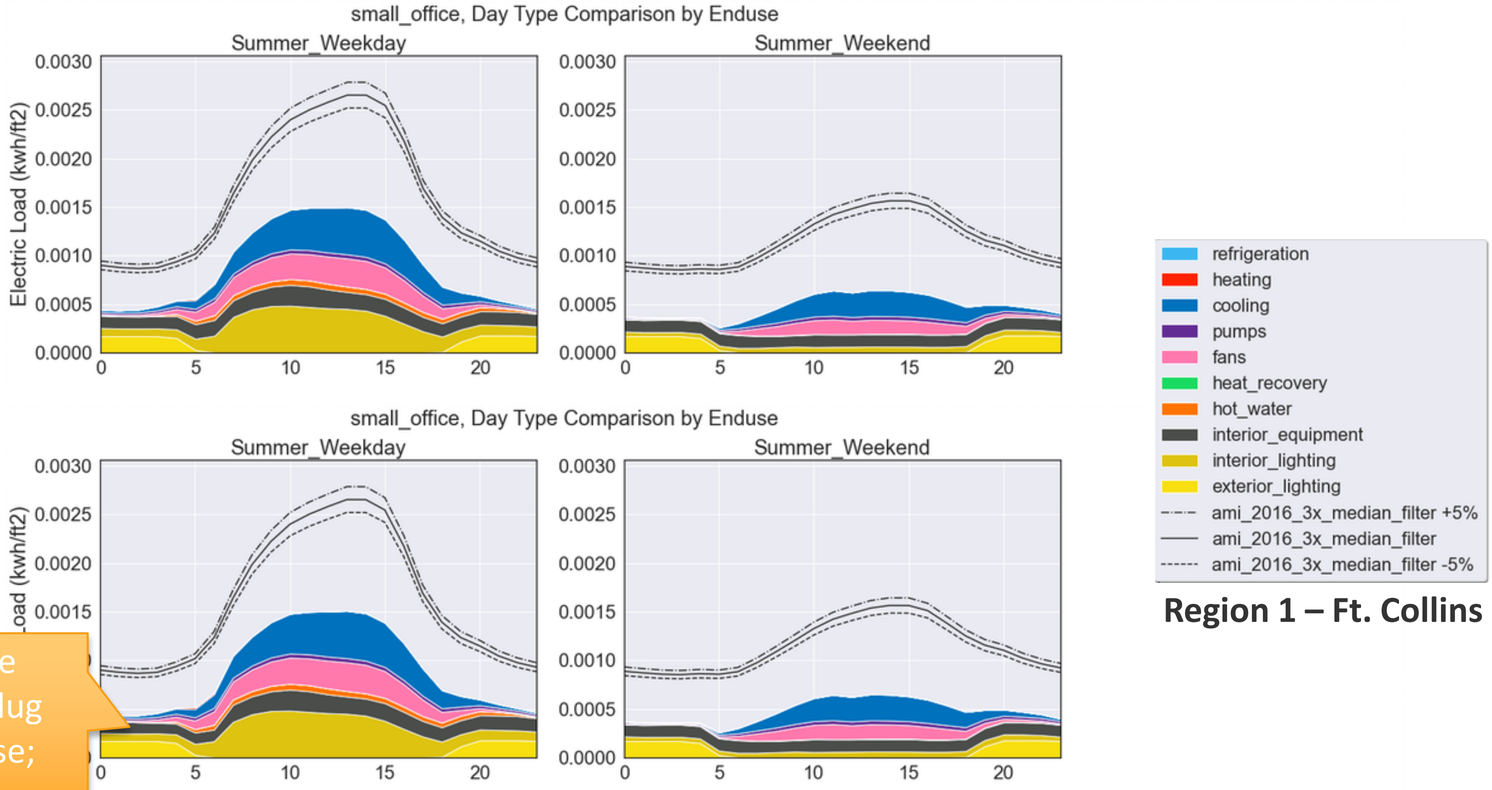
Region 1 – Ft. Collins

Retail

Impact: Plug Load Base-to-Peak Variability

Before

After



Region 1 – Ft. Collins

No noticeable difference in plug load energy use; mostly adds diversity to stock

Small Office

Update: Exterior Lighting Power Density

Task	Affected Building Type	Considerations
Exterior lighting power density	buildings where exterior lighting is defined	• Lighting power density in two sub-categories (parking and entry canopy) of exterior lighting are updated. • Based on 2015 U.S. Lighting Market Characterization report.

Update: Exterior Lighting Power Density

- Various information from 2015 U.S. Lighting Market Characterization (LMC) report
- For parking applications (about 50% of total exterior lighting nationally)

Avg Parking Light System Power

216 W/system

Avg Parking Lit Hours

16 hrs/day

Total # of Parking Lamps

83,519,000 systems

Total lot/garage spots

610,000,000 lot-spots/nationwide
85,000,000 garage-spots/nationwide

Avg # of spots

13 lot-spots/system
2.5 garage-spots/system

Possible to derive,

216 W/system ÷ **13** lot-spots/system = 16.615 W/lots-spots

16.615 W/lots-spots ÷ **405 sqft/lot-spots** = **0.041 W/sqft (national average for parking lots only)**

Thornton, B. A., Wang, W., Lane, M. D., Rosenberg, M. I., & Liu, B. (2009). *Technical support document: 50% energy savings design technology packages for medium office buildings* (No. PNNL-19004). Pacific Northwest National Lab.(PNNL), Richland, WA (United States).

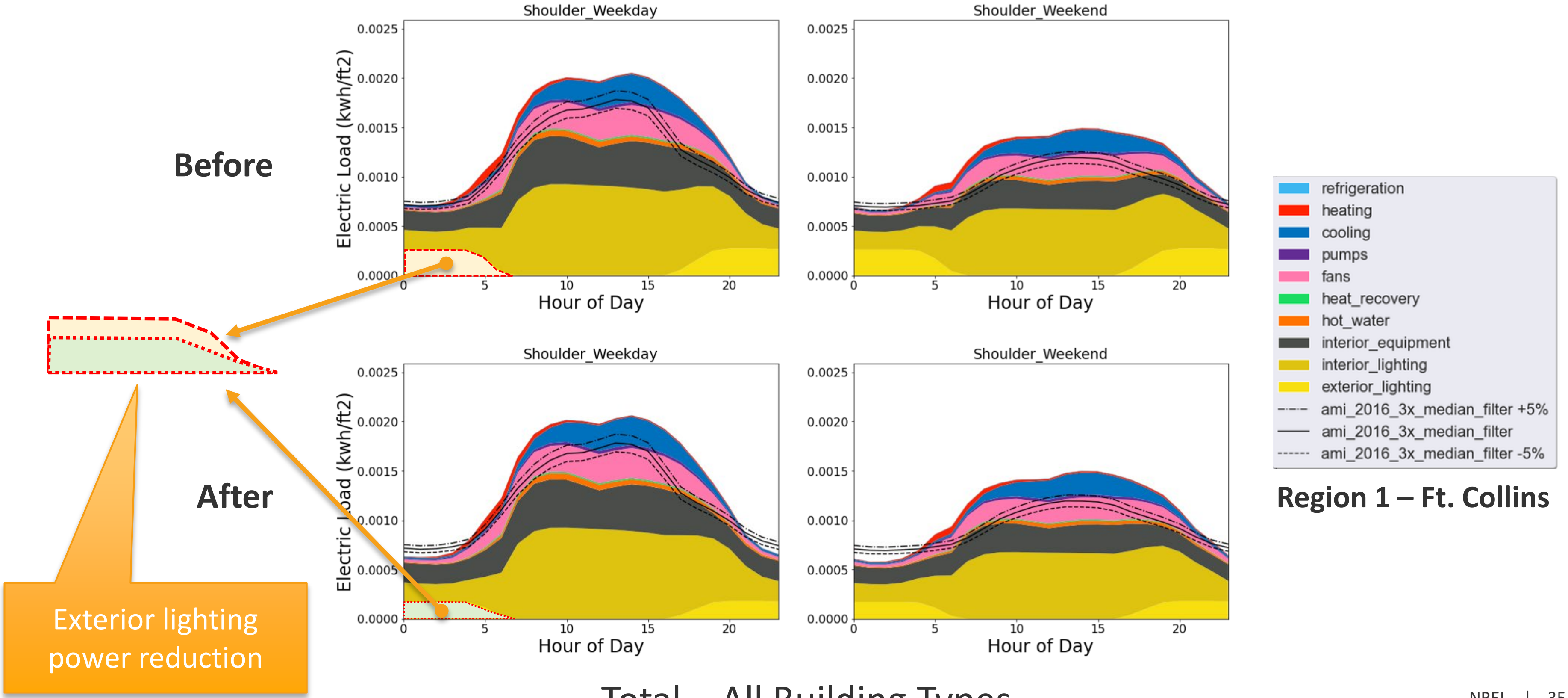
Update: Exterior Lighting Power Density

- ComStock (ASHRAE Standard) generally has much higher LPD definitions compared to LMC report.
- LPD definitions updated for each template based on weighted average.

LMC's weighted average = 0.041 W/ft^2

Standard	90.1 – 2004	90.1 – 2007	90.1 – 2010	90.1 – 2013	DOE Ref 1980-2004
# of Buildings	85652	96278	98128	28707	41235
Portion	24%	28%	28%	8%	12%
Original LPD (W/ft^2)	0.15	0.15	0.1	0.1	0.18
Revised LPD (W/ft^2)	0.045	0.045	0.030	0.030	0.055

Update: Exterior Lighting Power Density



Region 1 – Ft. Collins

Total – All Building Types

Update: Warehouse Operation Schedules

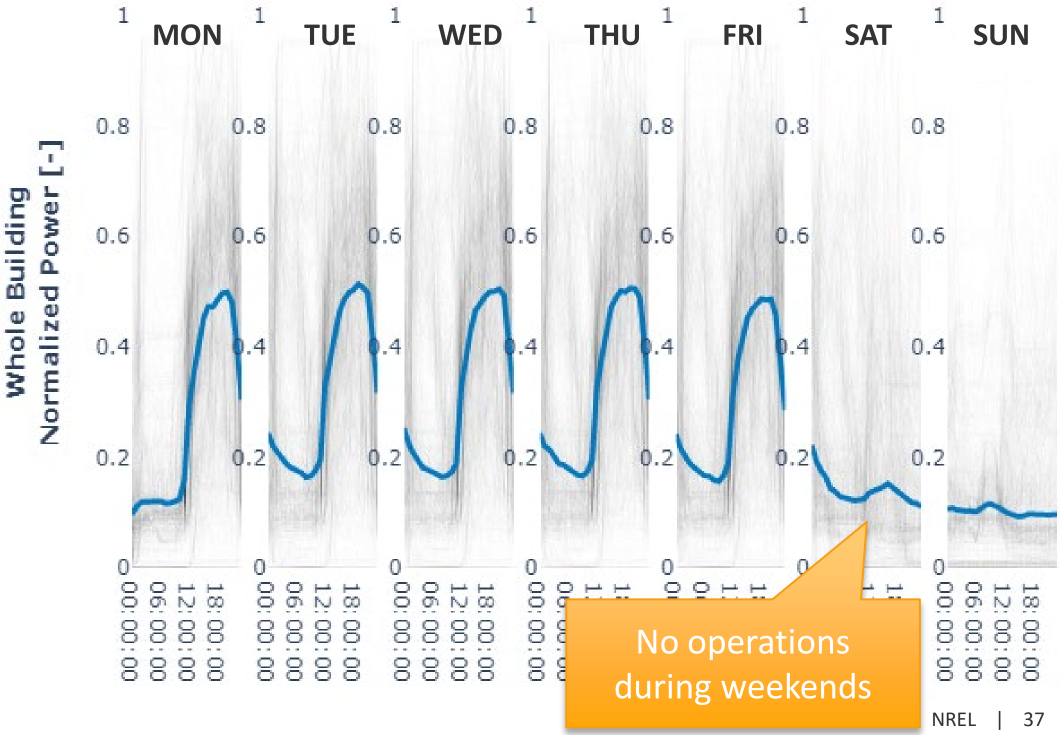
Task	Affected Building Type	Considerations
Warehouse schedules (lighting, plug load, occupancy)	warehouse	• Operations of warehouses were reviewed and reconsidered in terms of day types between weekdays and weekends.

Update: Warehouse Operation Schedules

- Based on end-use data (shown below) and AMI data (Fort Collins, Seattle, Portland), weekend warehouse operation assumptions in models disagreed with findings from utility data.

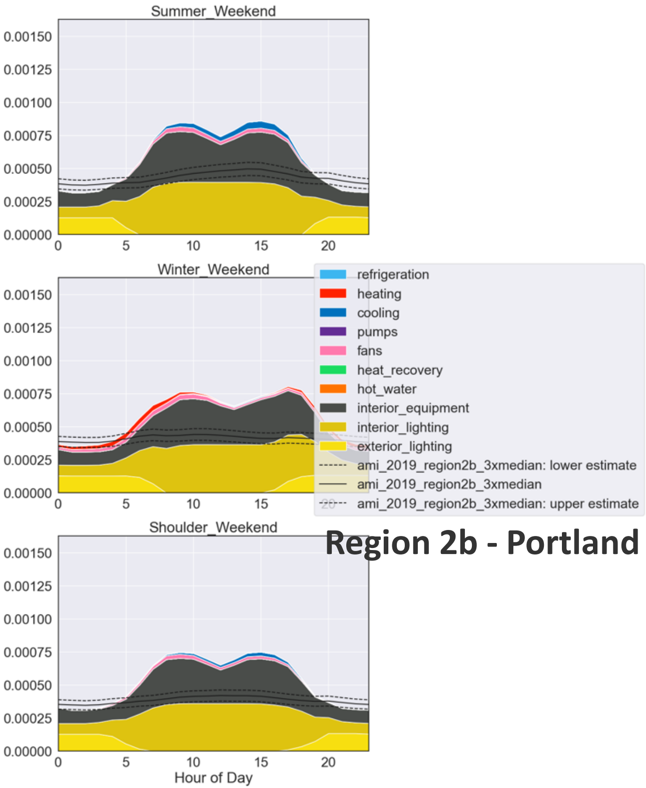
Warehouses in end-use data

Census Division	US State	Counts
EastNorthCentral	IL	2
MidAtlantic	PA	3
Mountain	CO	2
Pacific	CA	11
	OR	1
SouthAtlantic	MD	1
WestSouthCentral	LA	3
	TX	2



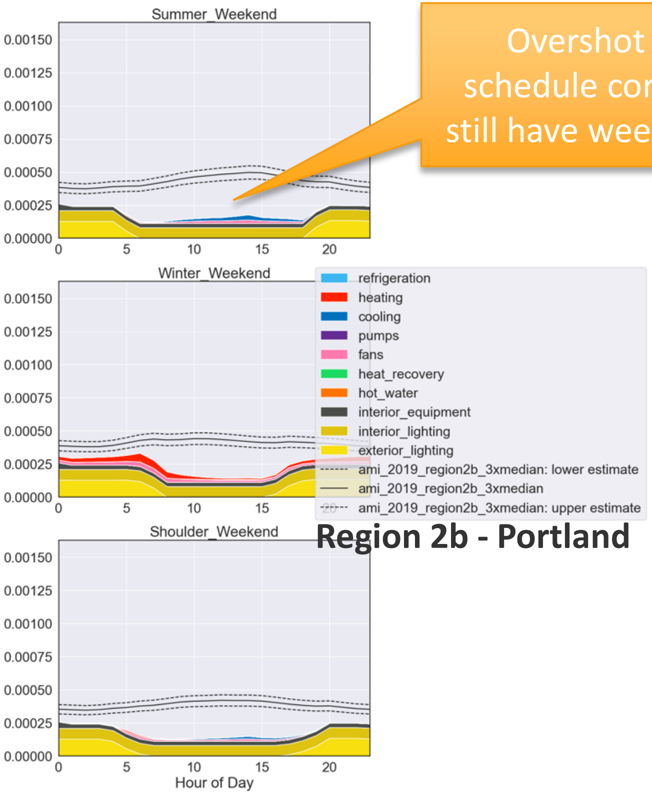
Update: Warehouse Operation Schedules

Before



Region 2b - Portland

After



Region 2b - Portland

Overshot warehouse schedule correction; some still have weekend operation

HVAC Updates

Update: HVAC Controls

Task	Affected Building Type	Methods
Updated fan cycling controls for PSZ systems	All buildings with PSZ systems	Before, systems were always on following HVAC operating hours, now fan are adjusted to provide ventilation only when occupied
DCV bug fix	Buildings with VAV systems that use 90.1-2010 or 2013	DCV controls were not enabled and are now enabled per 90.1 standards

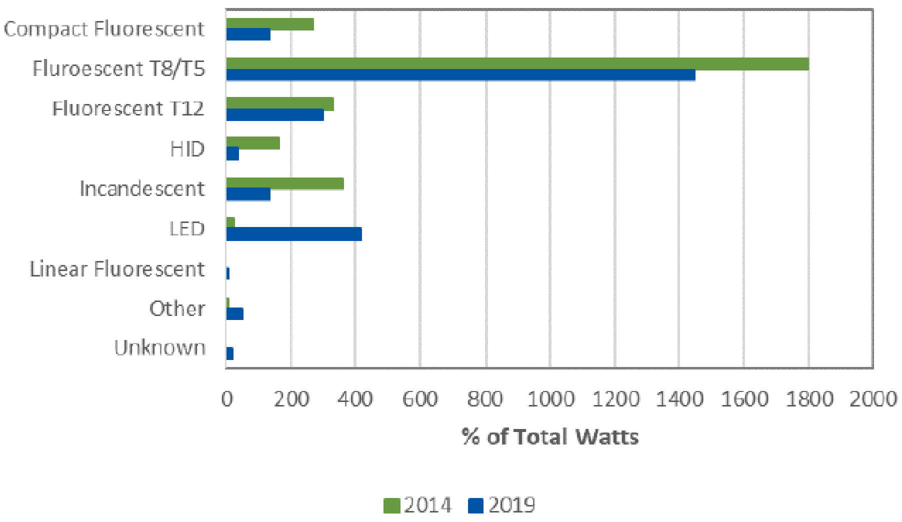
Minimal changes to loads because of limited applicability of control changes

Lighting Power Density Analysis

Lighting Power Density Comparison

- Lighting constitutes the majority of energy use
- Lighting technologies have changed much faster than the rest of commercial building technologies
- ComStock uses a technology rollover model, but only has standards up to 90.1-2013

Figure 28. Indoor Lighting Wattage by Lamp Type



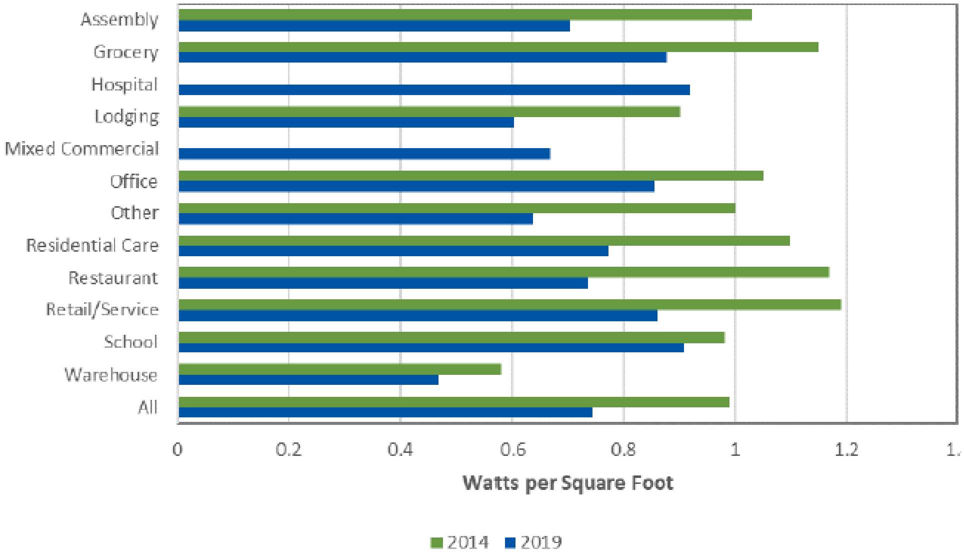
"...the major change over time involved a significant transition to LED lighting power, which only represented 20 MW in 2014 (1% of regional commercial indoor lighting power). By 2019, that value had increased **by more than 20 times** to 419 MW, or 16% of the regional total."

Source: NEEA Commercial Building Stock Assessment (CBSA) 2019

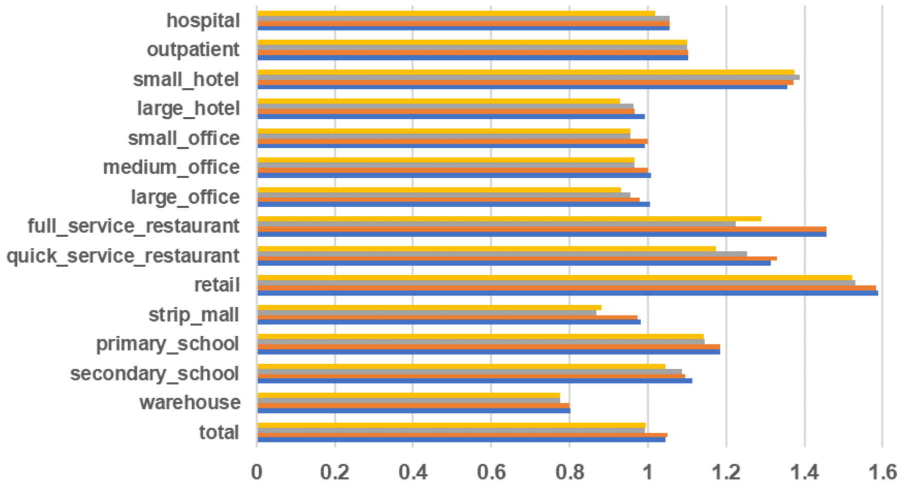
Lighting Power Density – To Be Implemented

- CBSA shows a 0.24 W/ft^2 decrease (0.99 → 0.74 W/ft^2) between 2014 and 2019
- ComStock values, in 2019, show a <0.1 W/ft^2 decrease between 2016 and 2019
- ComStock LPDs are substantially higher than CBSA in key building types (warehouse, retail)
- Will address by adding 90.1-2016, 90.1-2019 and a more aggressive rollover model

Figure 31. Lighting Power Density Reduction Between 2014 and 2019[a]



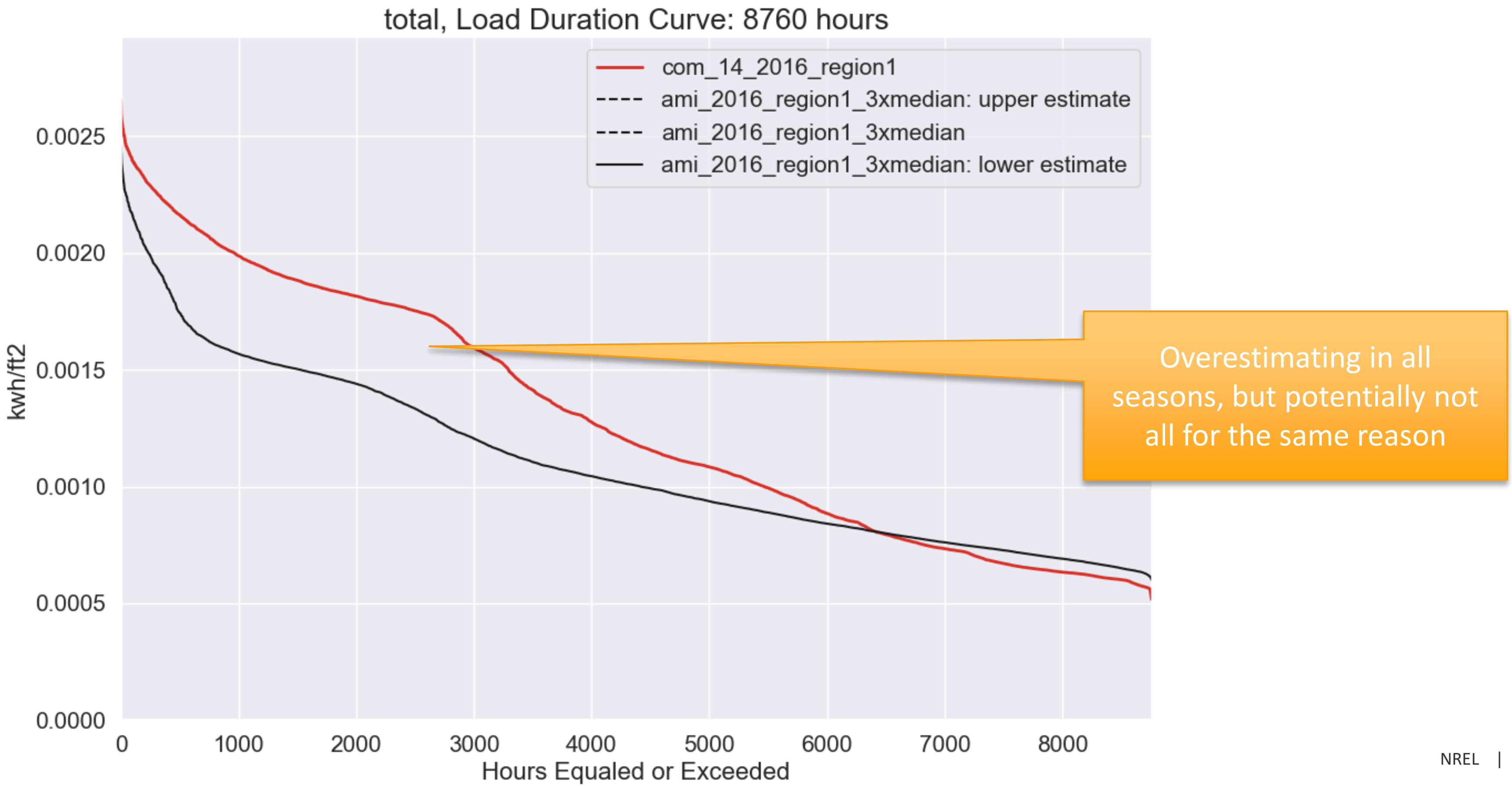
ComStock Average LPD by Building Type (W/sf)



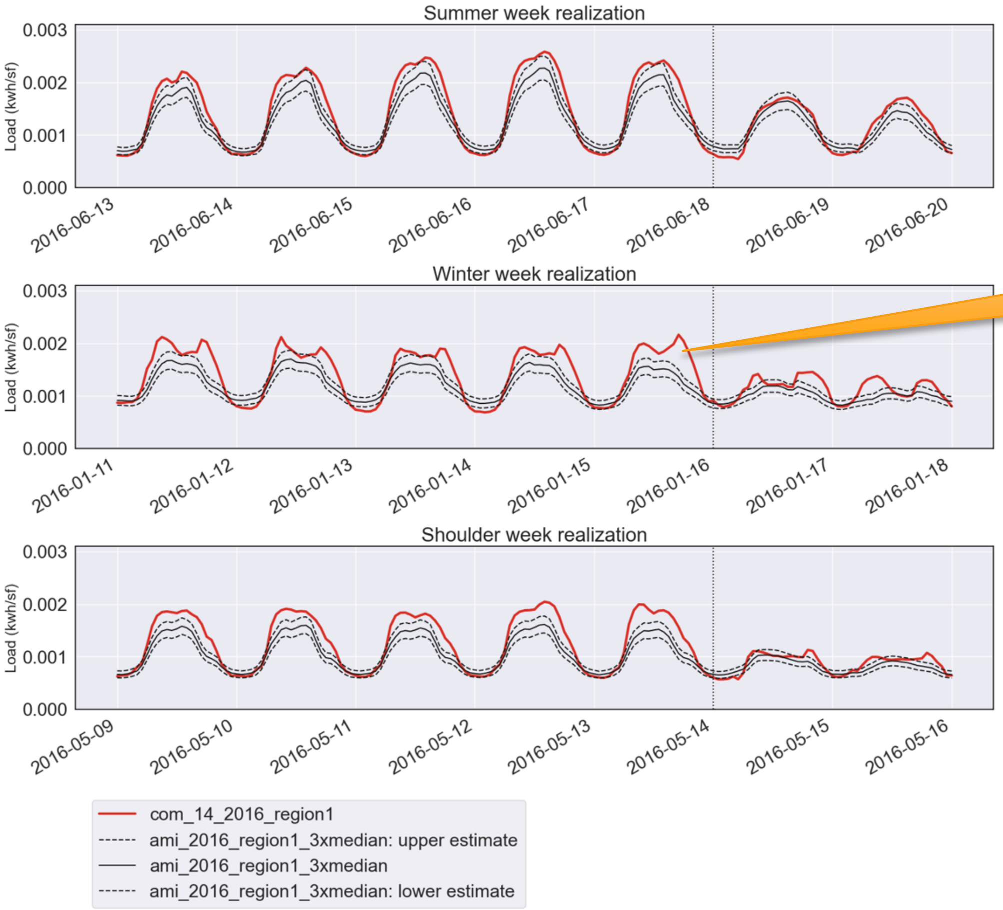
Source: NEEA Commercial Building Stock Assessment 2019

Total Commercial Stock Status

Region 1 – Fort Collins

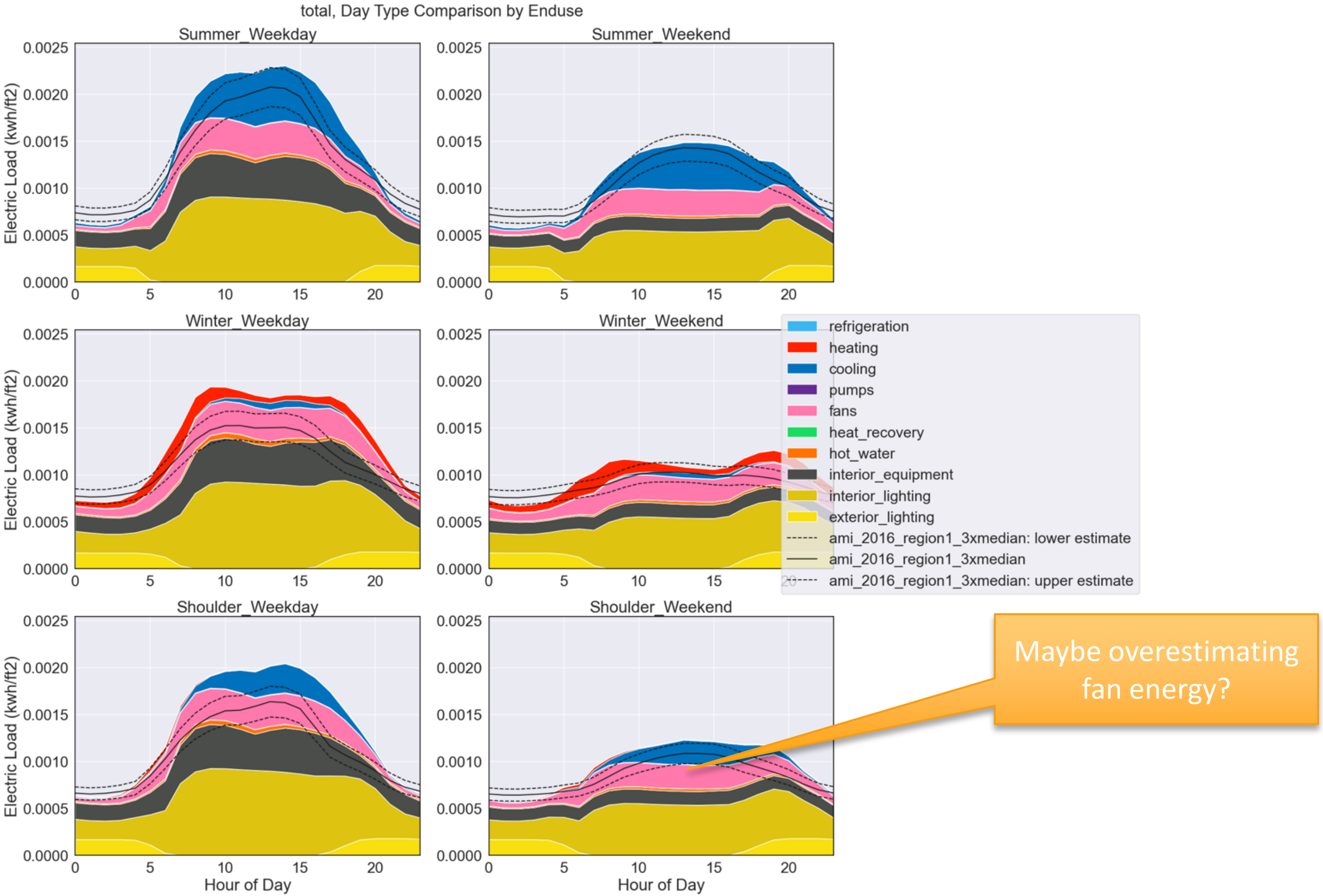


Region 1 – Fort Collins

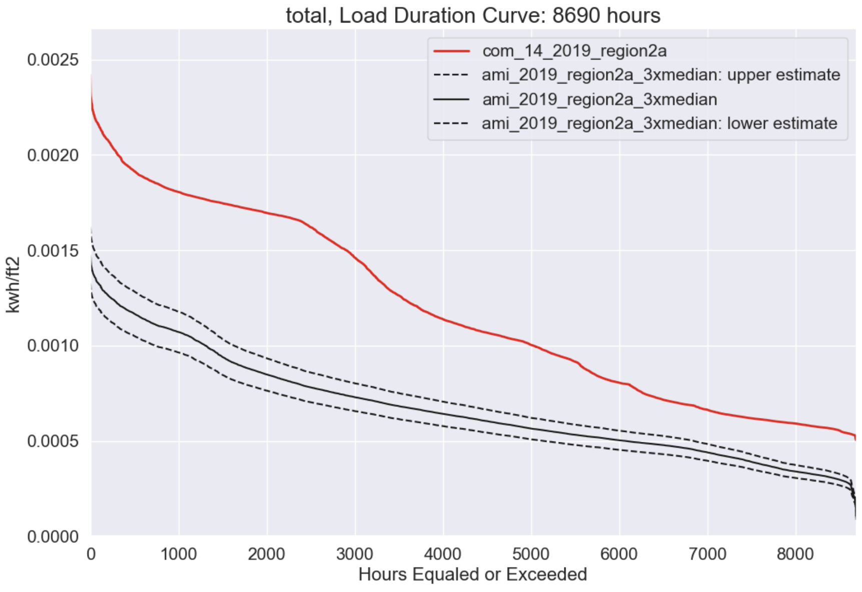


Need to review shape to understand main drivers

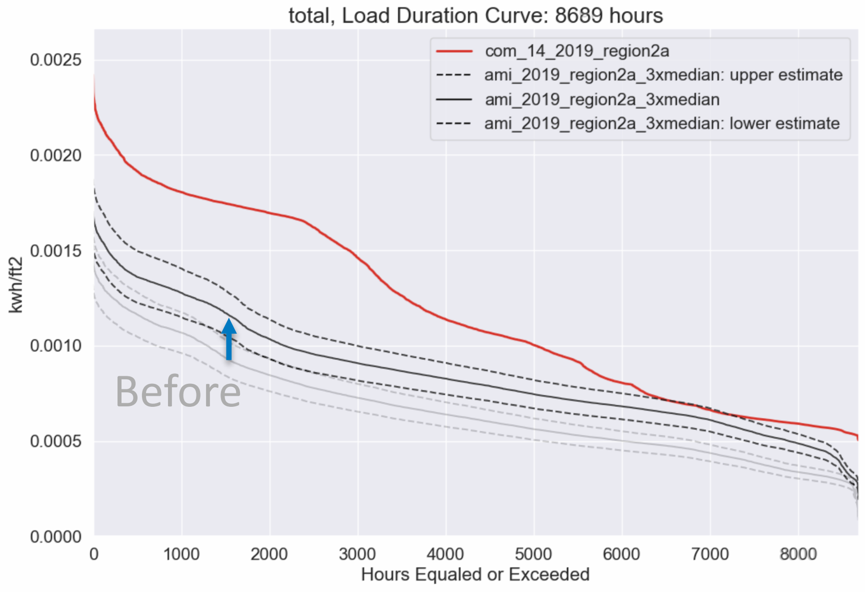
Region 1 – Fort Collins



Region 2a – Seattle – Correction Since 2/28



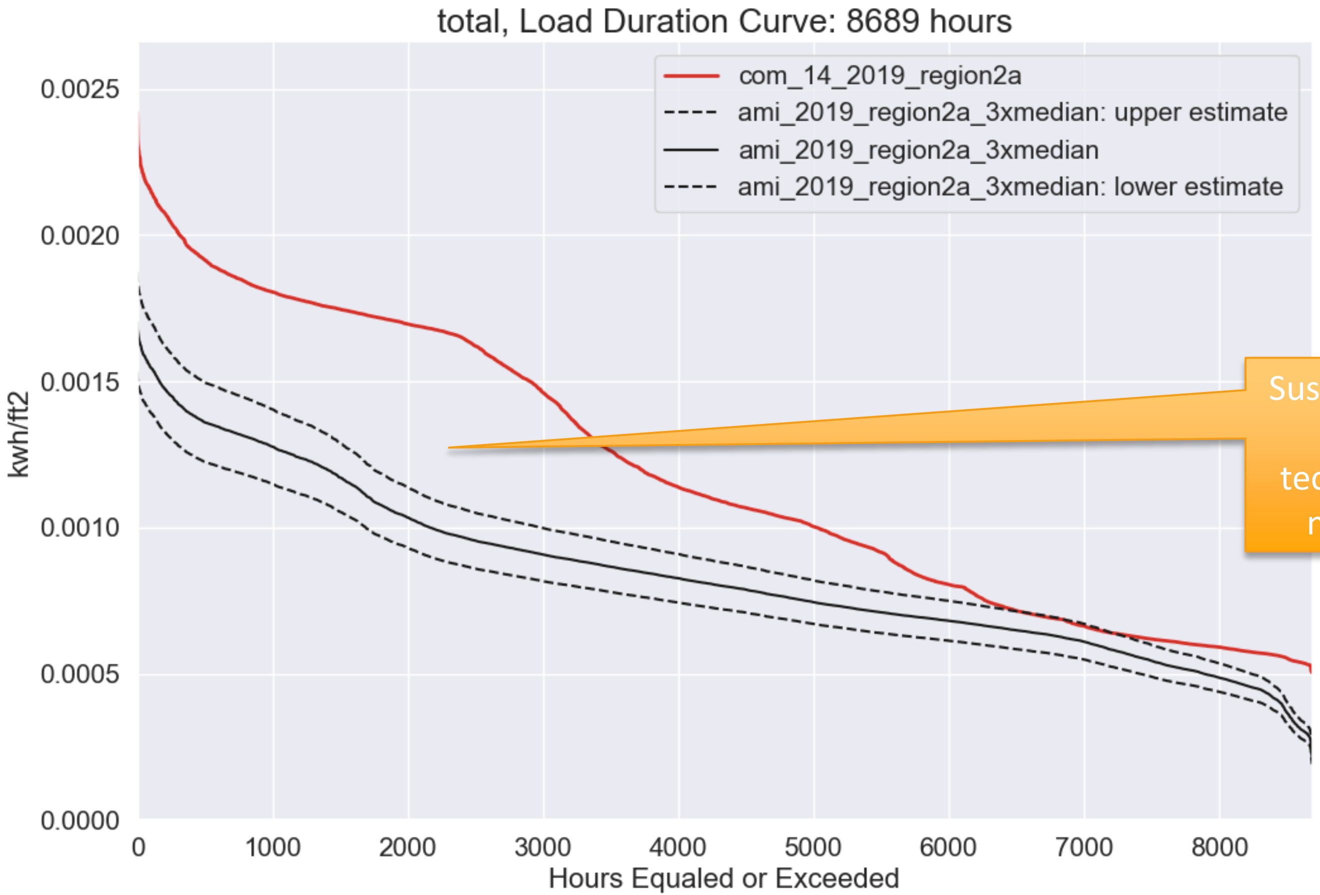
Before correction



After correction

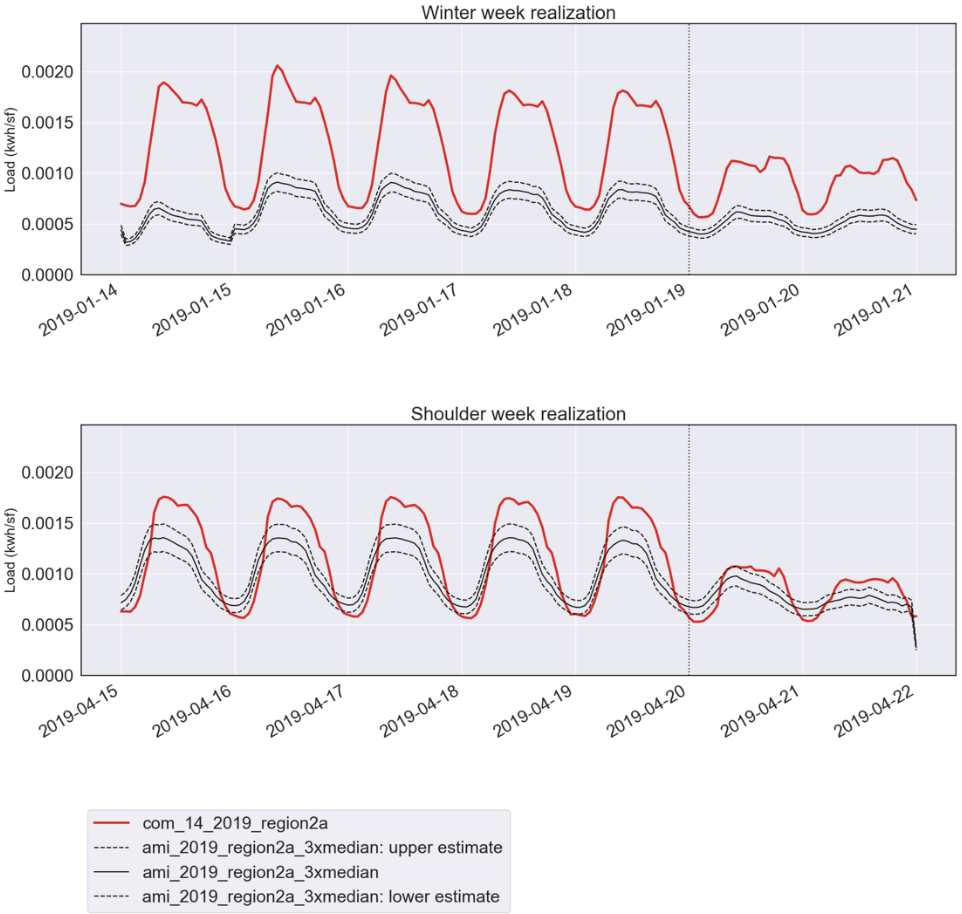
- Suspicions about AMI EUIs led to additional investigation of building type mapping
- Seattle was able to identify issue and correct mapping
- AMI aggregations make more sense alone and compared to PGE

Region 2a - Seattle

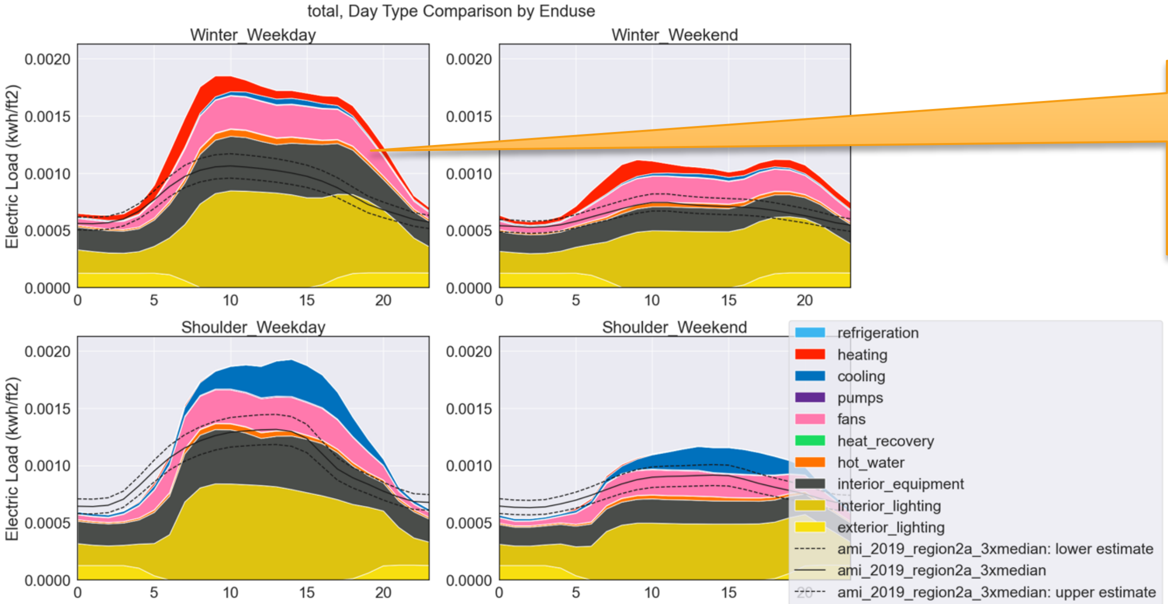


Suspect much of this error due to aggressive lighting technology changes in pacific northwest in last 10 years

Region 2a - Seattle

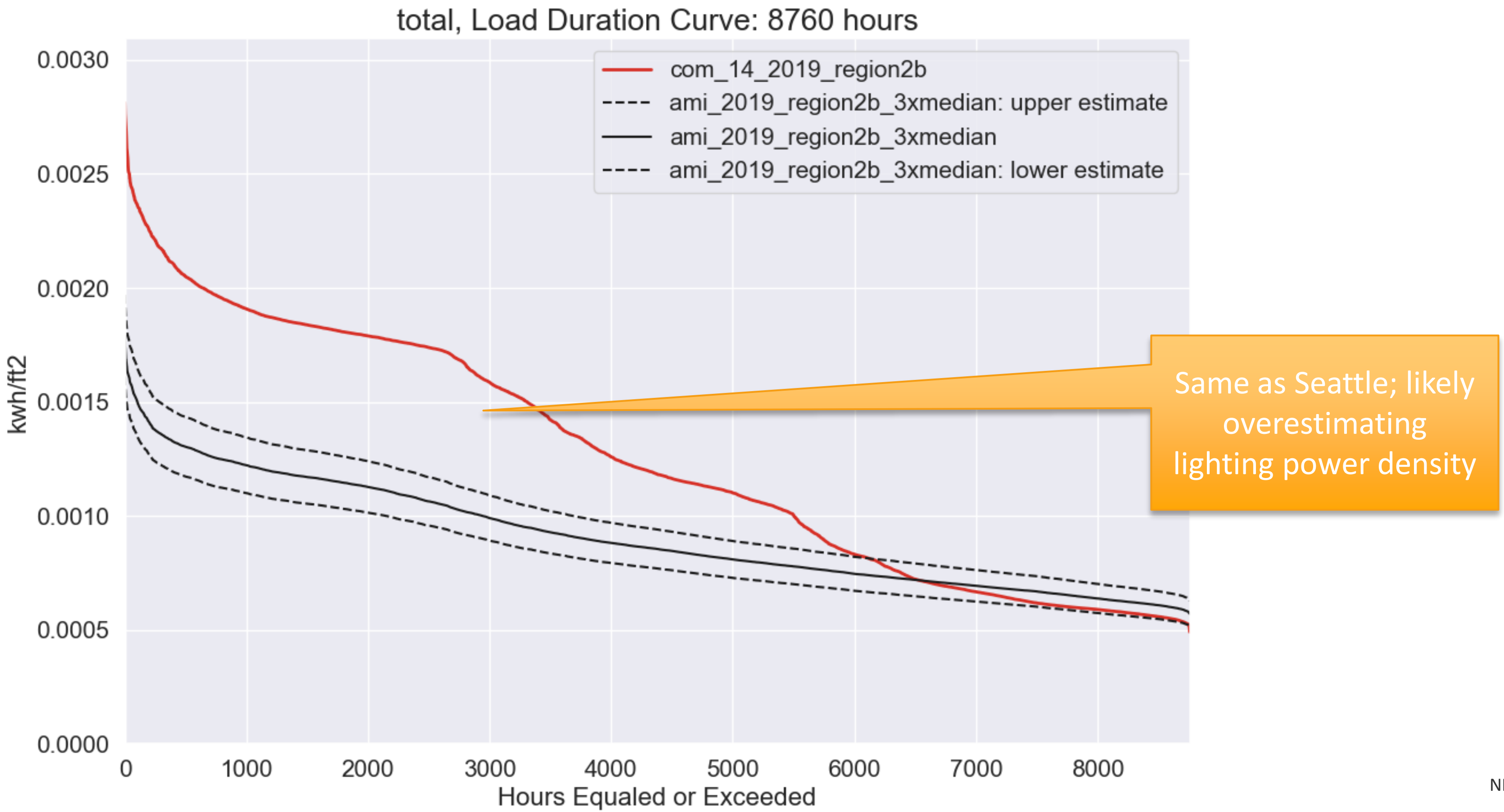


Region 2a - Seattle

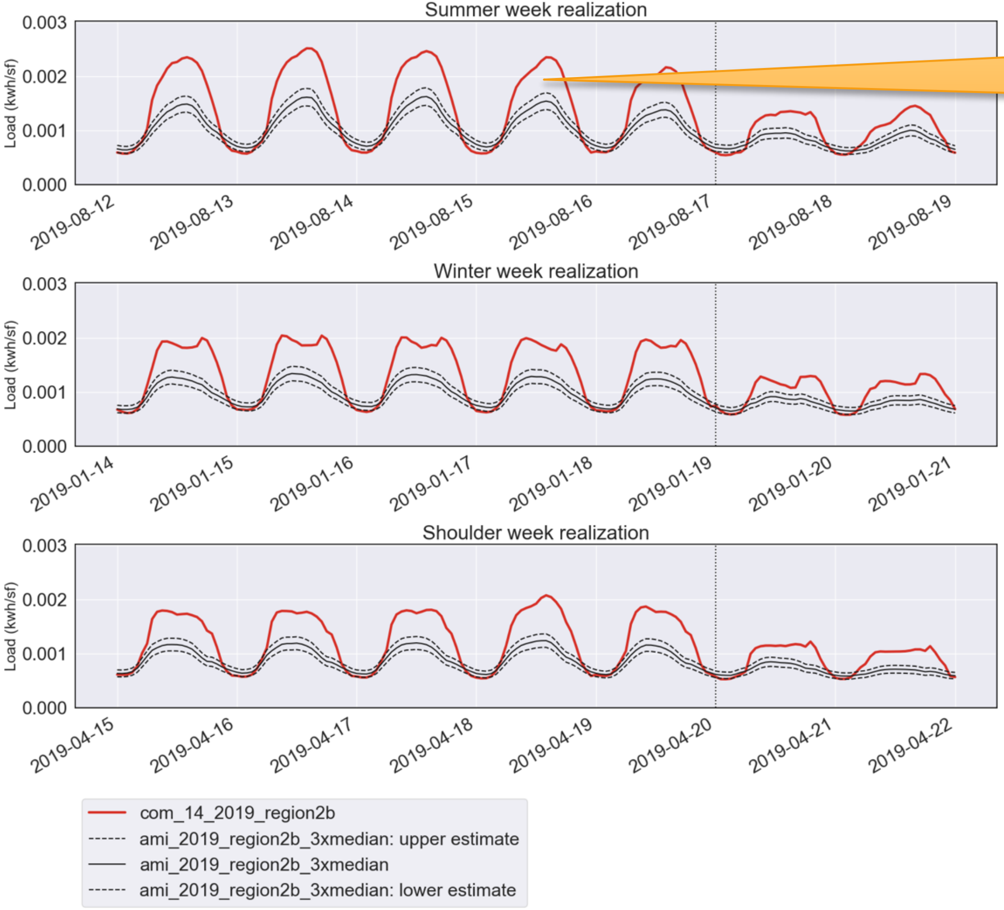


Suspect much of this error due to aggressive lighting technology changes in pacific northwest in last 10 years

Region 2b - Portland

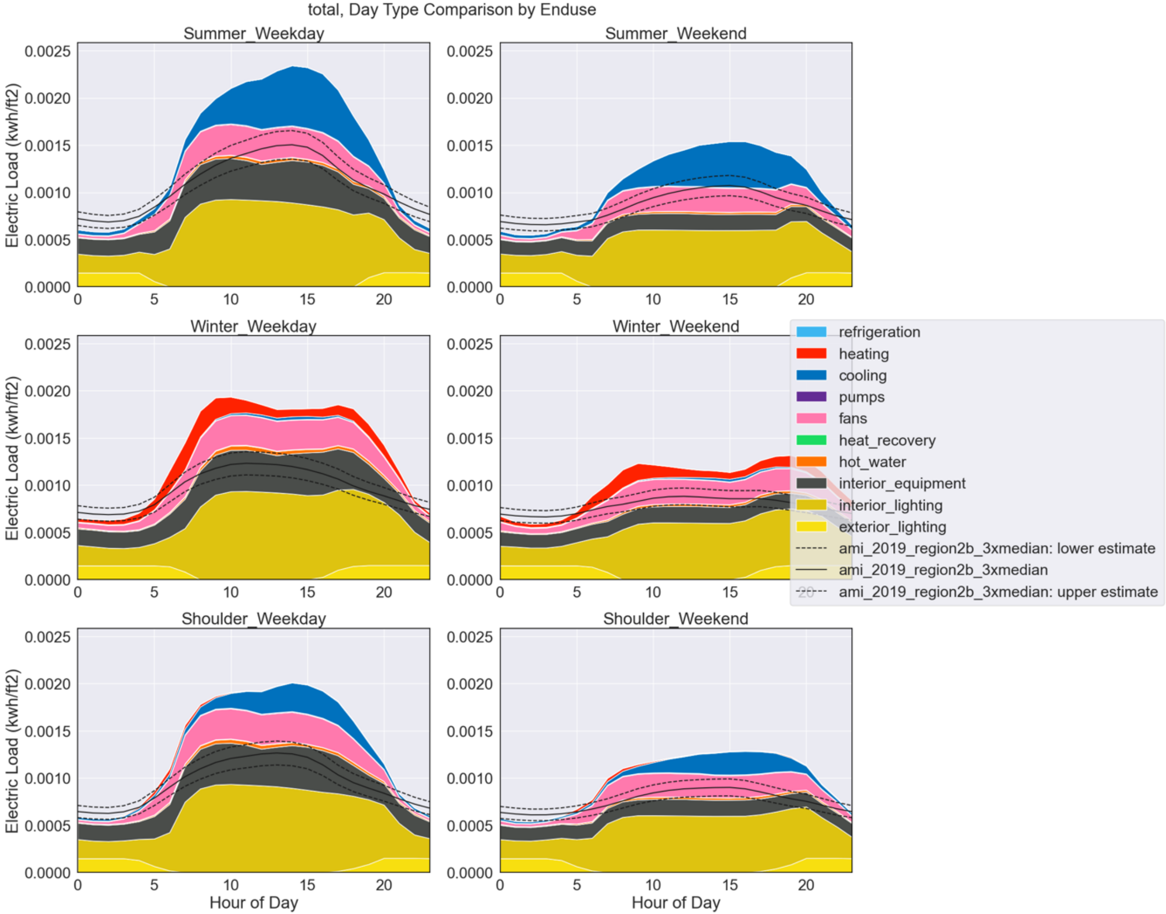


Region 2b - Portland



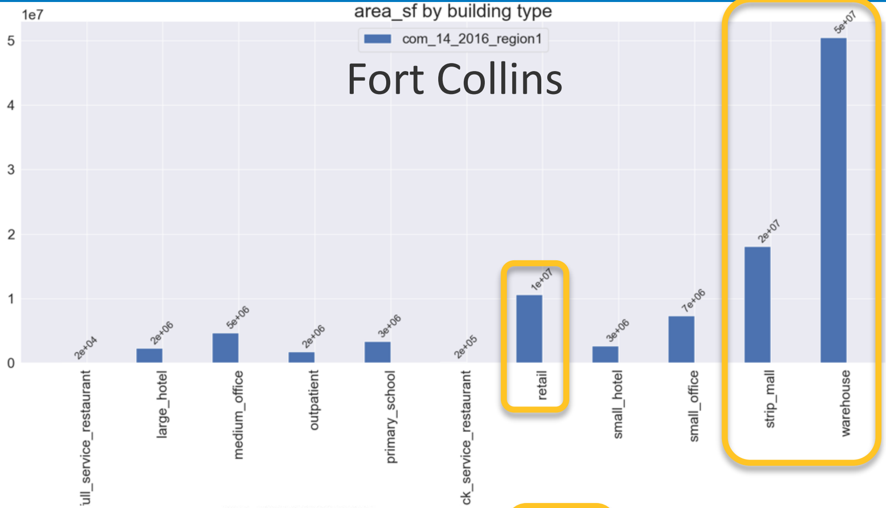
Likely overestimating lighting power density

Region 2b - Portland

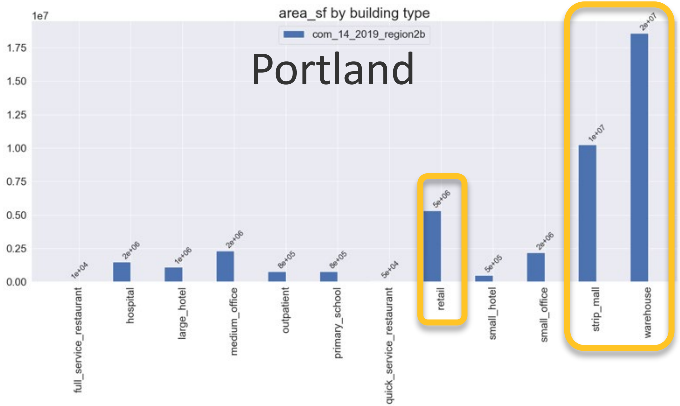


Building Type Focus

Dominant Building Types by Area

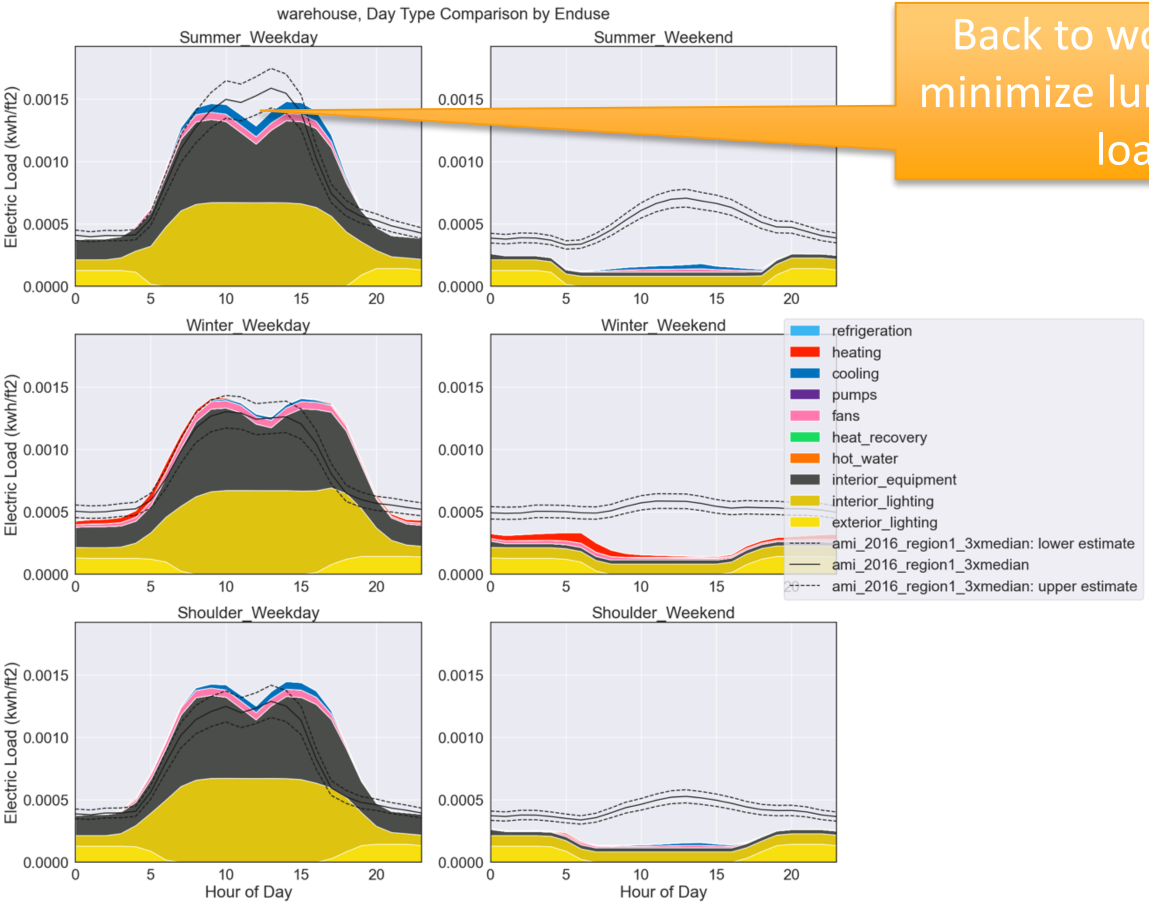


Warehouse, Strip Mall & Retail dominate building area for all 3 datasets



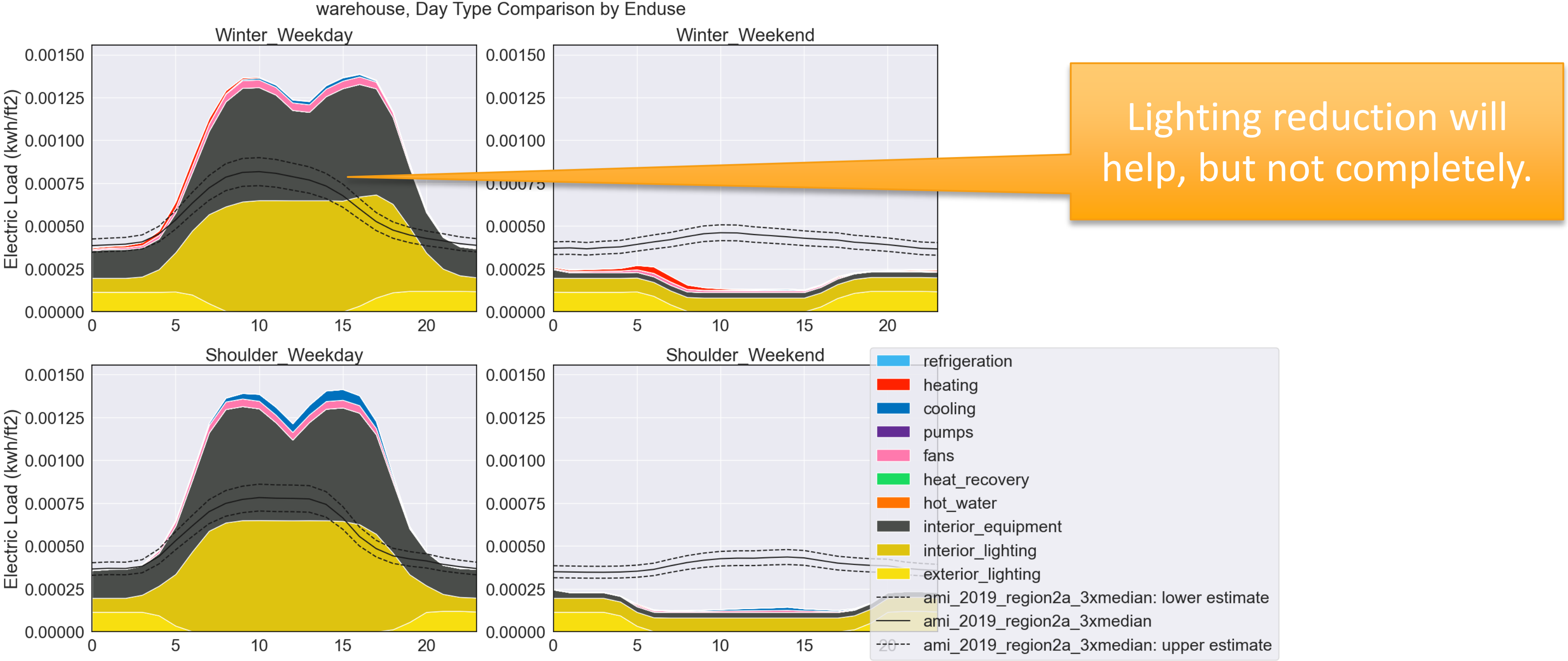
Warehouse

Warehouse – 1 Fort Collins

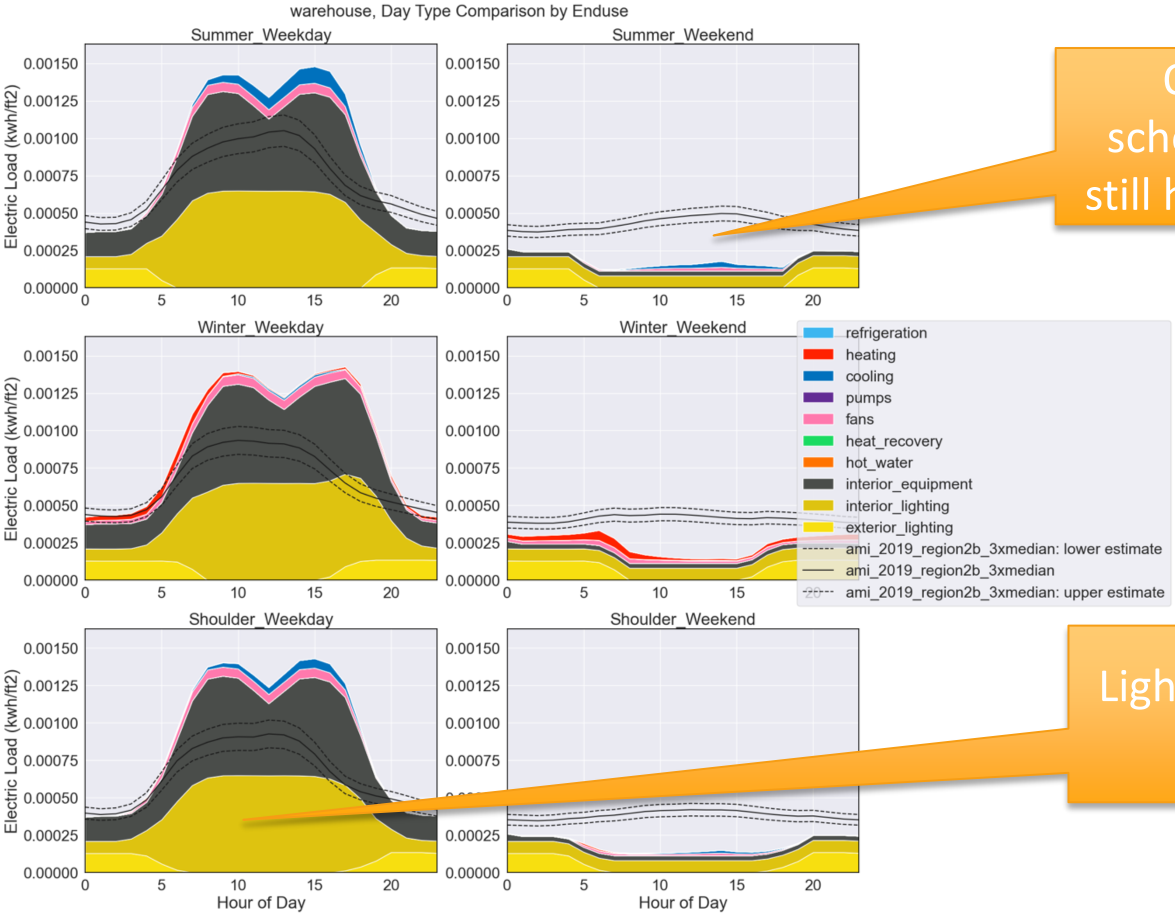


Back to work! Need to minimize lunch break plug load dip

Warehouse – 2A Seattle



Warehouse – 2B Portland

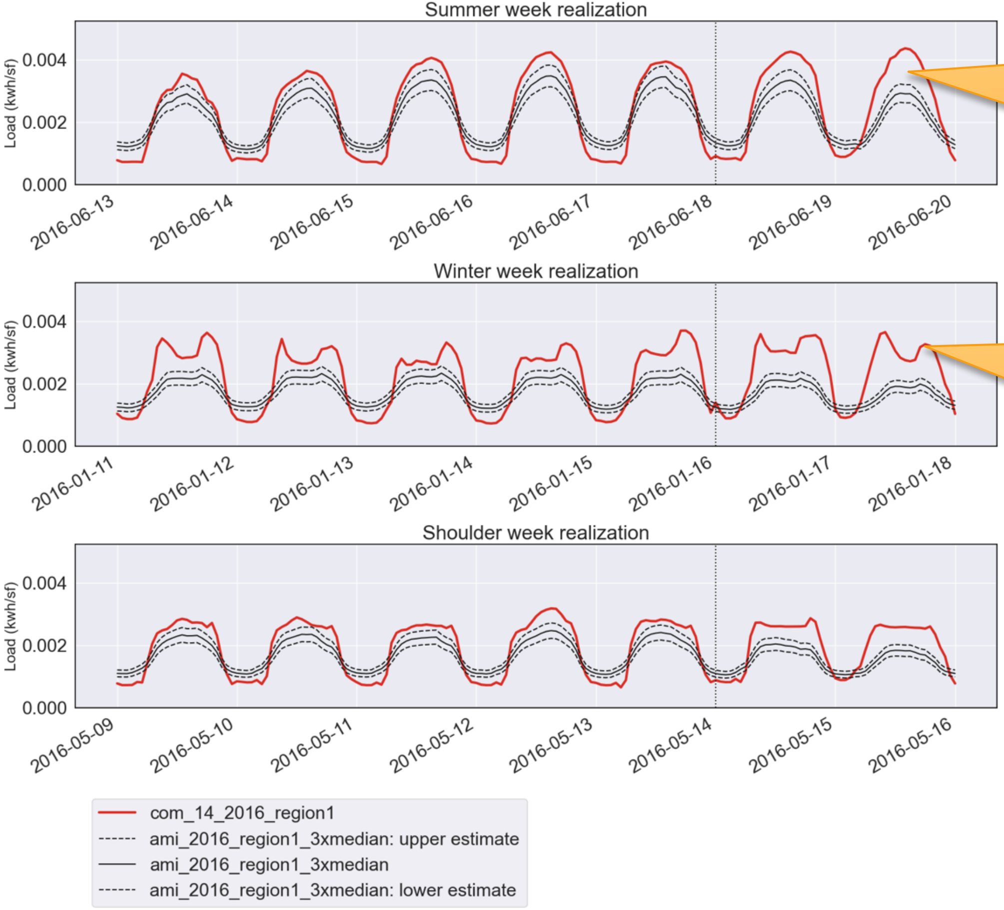


Overshot warehouse schedule correction; some still have weekend operation

Lighting power density reduction should help significantly

Strip Mall

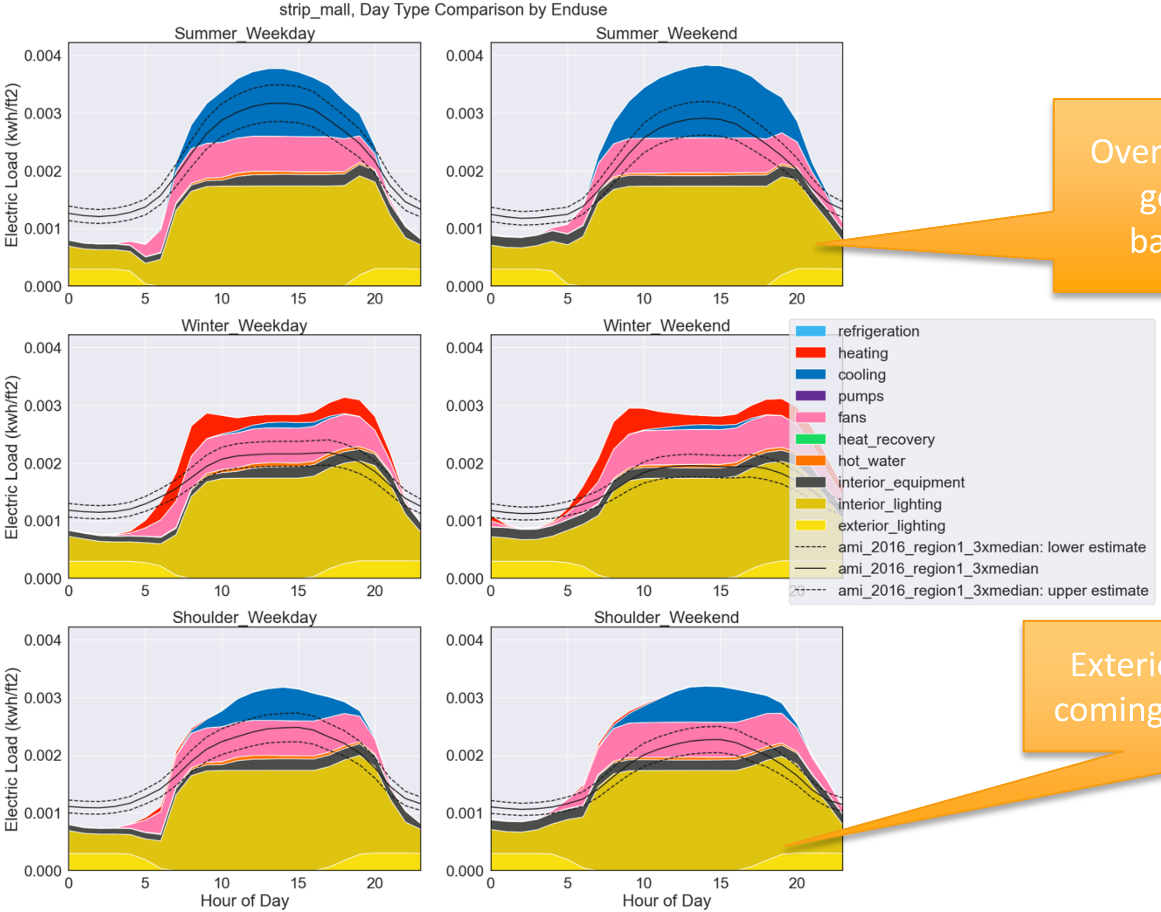
Strip Mall – 1 Fort Collins



Seems like we're getting weekend operating hours correct, but we're overstating what is happening during those hours, especially Sundays.

Overshooting by quite a bit (more so than other seasons and retail winter). More pronounced "dog ears." Similar thing happening on weekends as in summer.

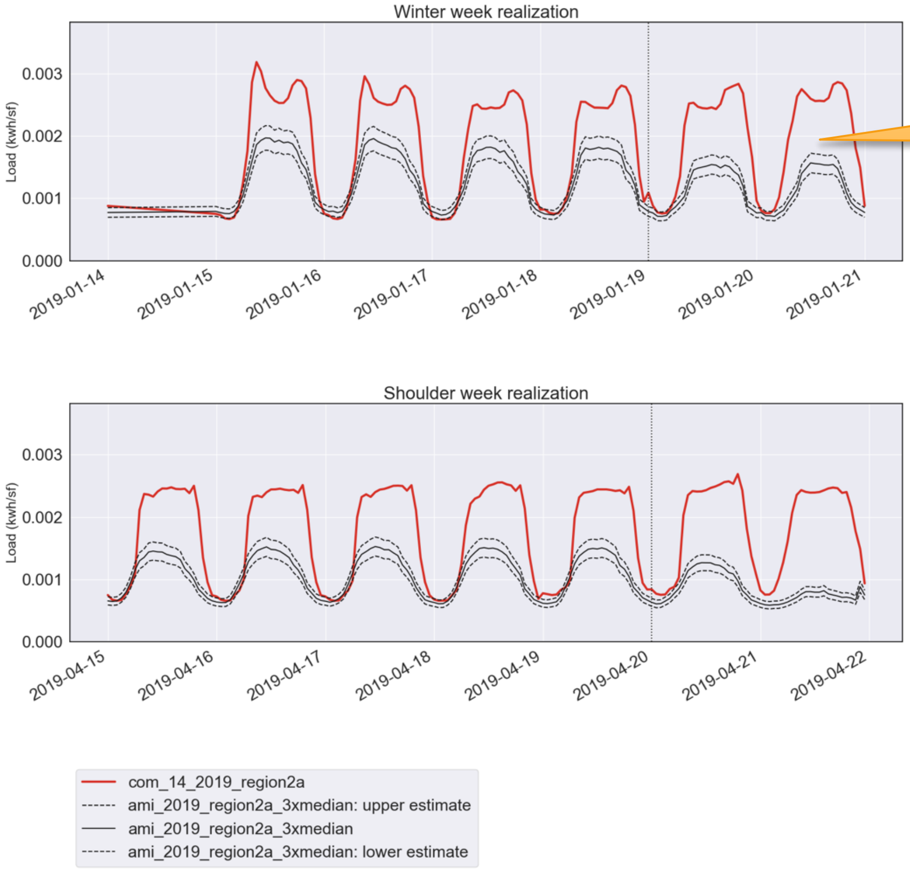
Strip Mall – 1 Fort Collins



Overshooting, but shape looks good. Still missing some baseload. Check lighting?

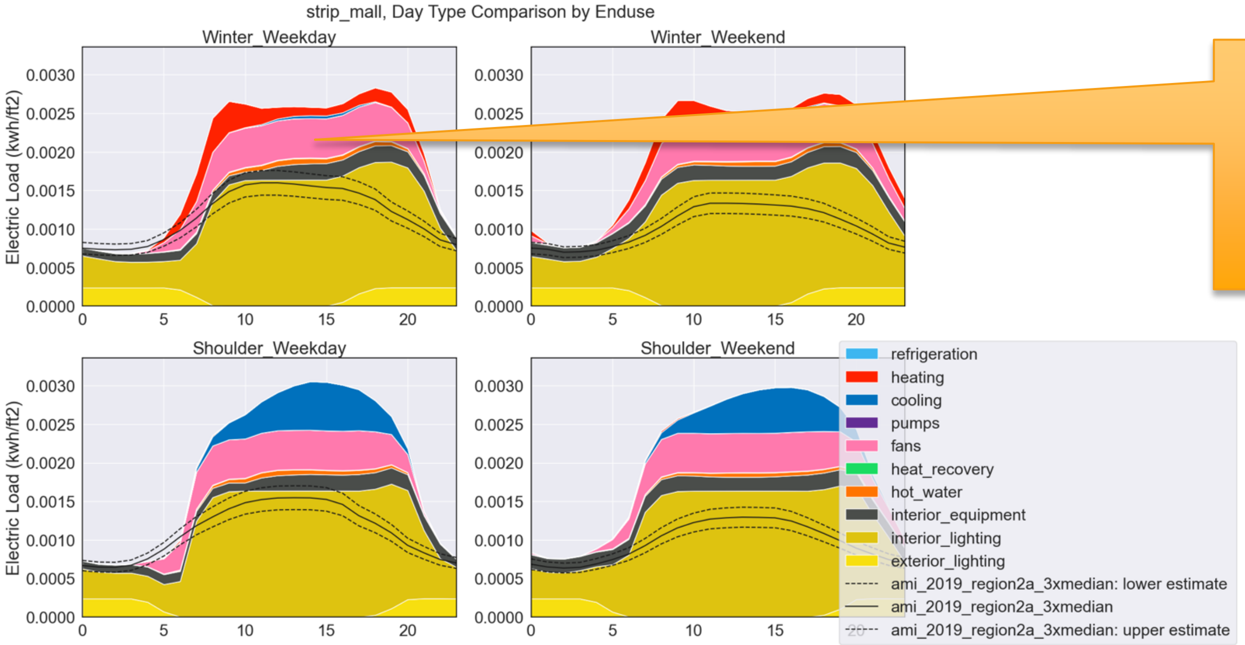
Exterior lighting still looks like it's coming on too early in the evening.

Strip Mall – 2A Seattle



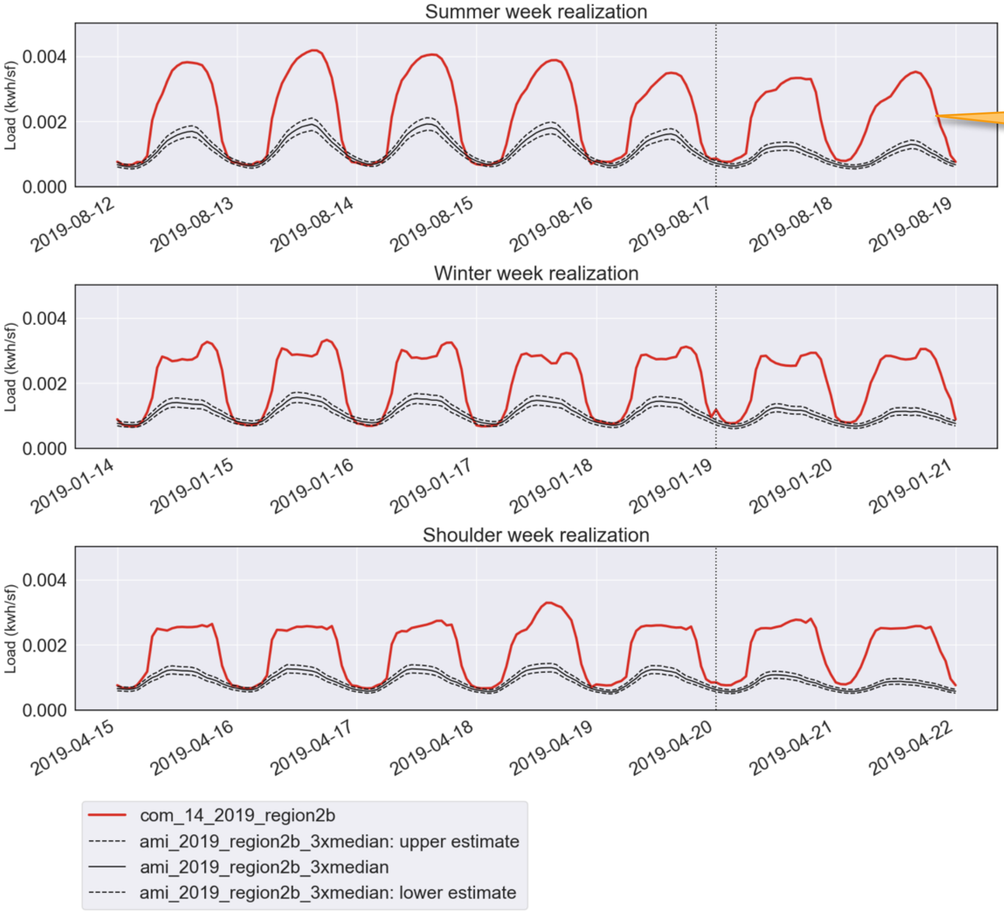
Lighting reduction will help, but not completely. Need to look at HVAC operation as well.

Strip Mall – 2A Seattle



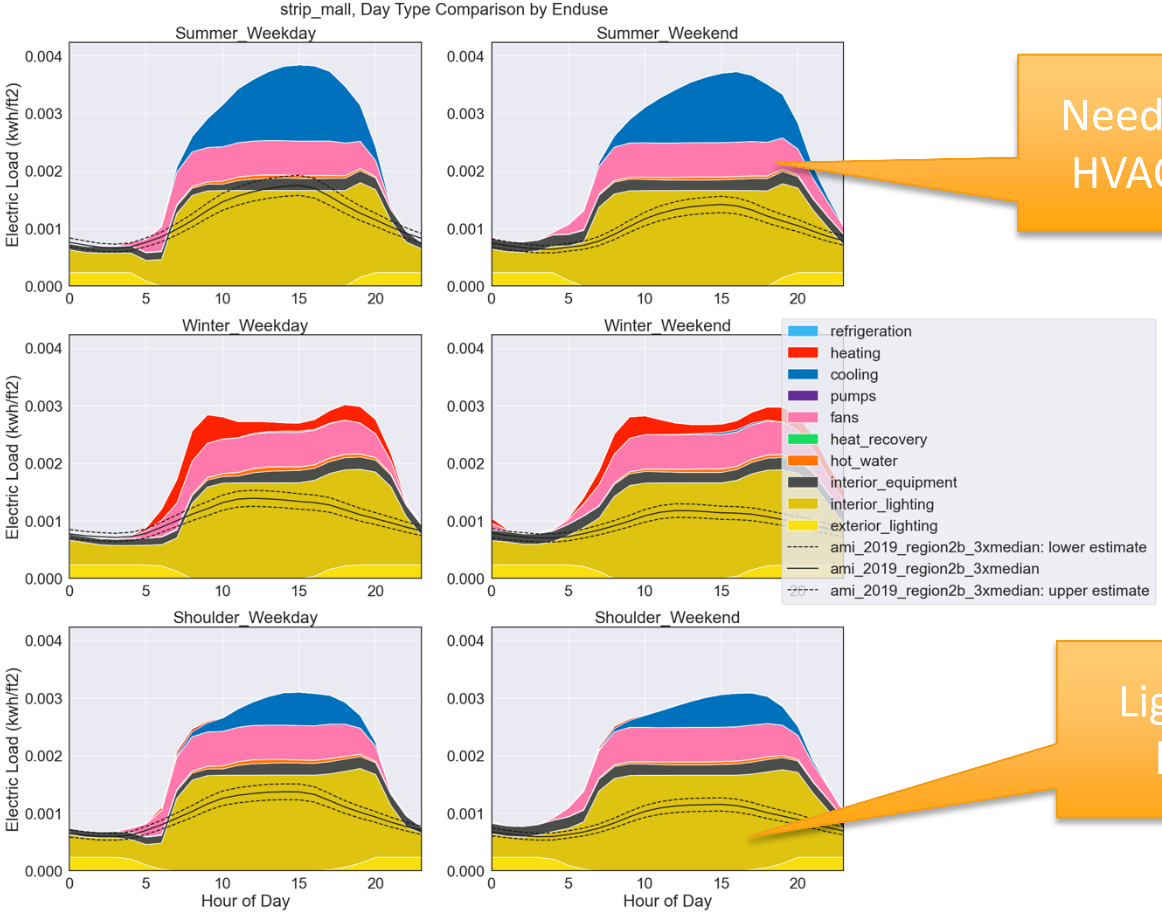
Lighting reduction will help, but not completely. Need to look at HVAC operation as well.

Strip Mall – 2B Portland



Lighting reduction will help, but not completely

Strip Mall – 2B Portland

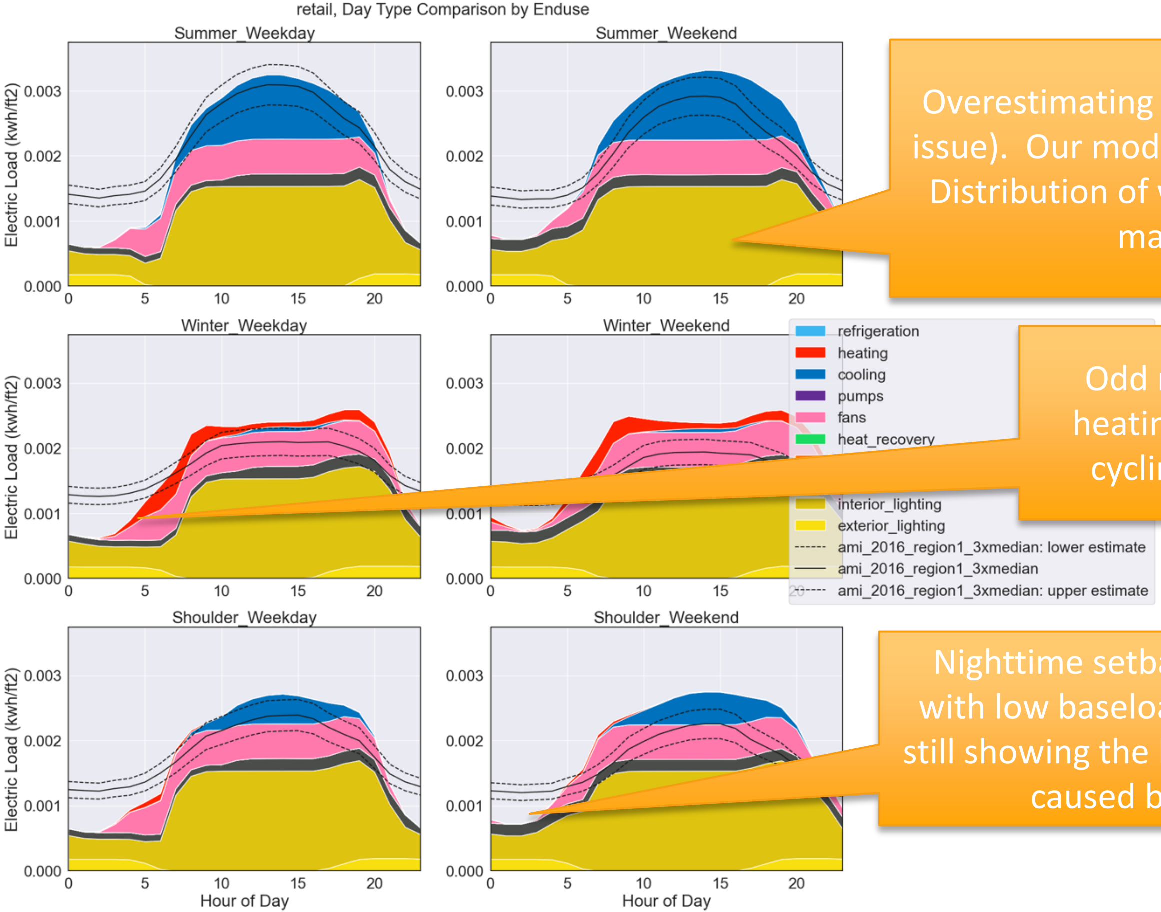


Need to investigate fan and HVAC operation schedules

Lighting reduction should help, but not entirely.

Retail

Retail – 1 Fort Collins

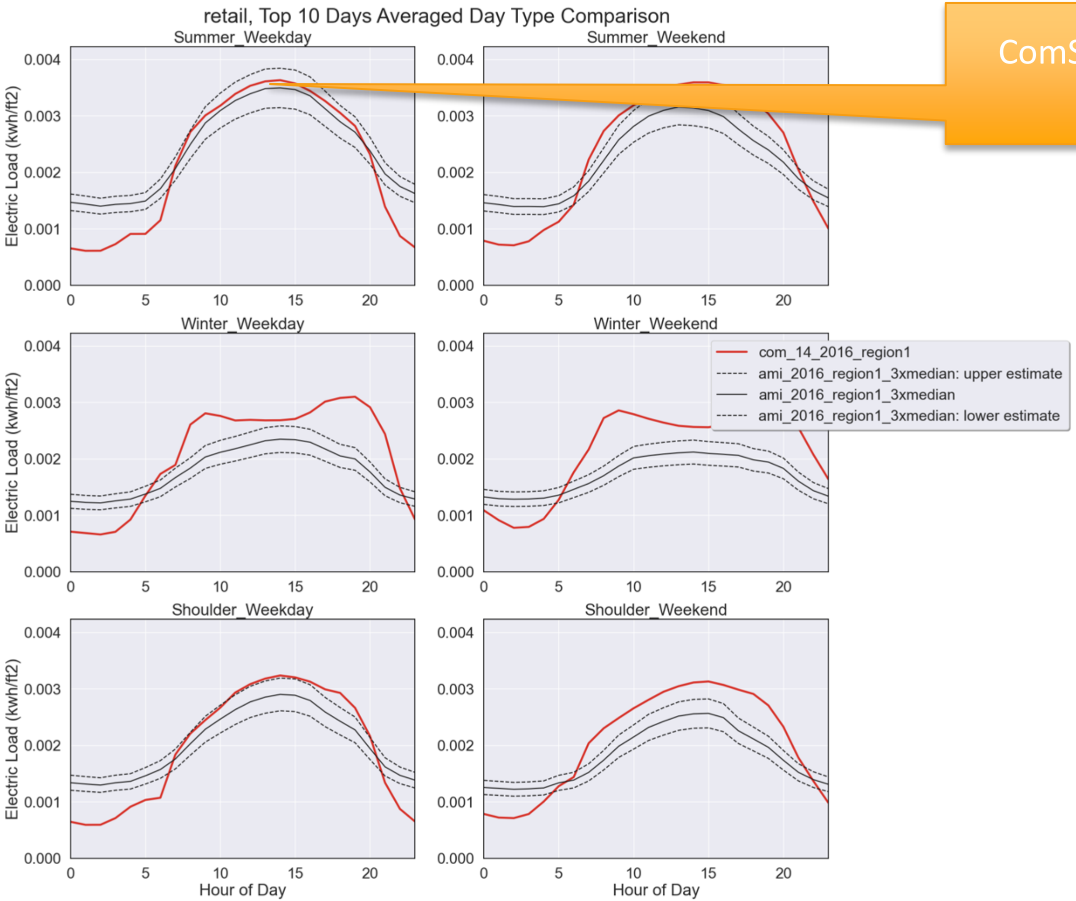


Overestimating on weekends (may be lighting issue). Our models have more weekend usage. Distribution of weekend operating schedules may need updating.

Odd nighttime trend with heating and fans. Could be cycling or truck unloads?

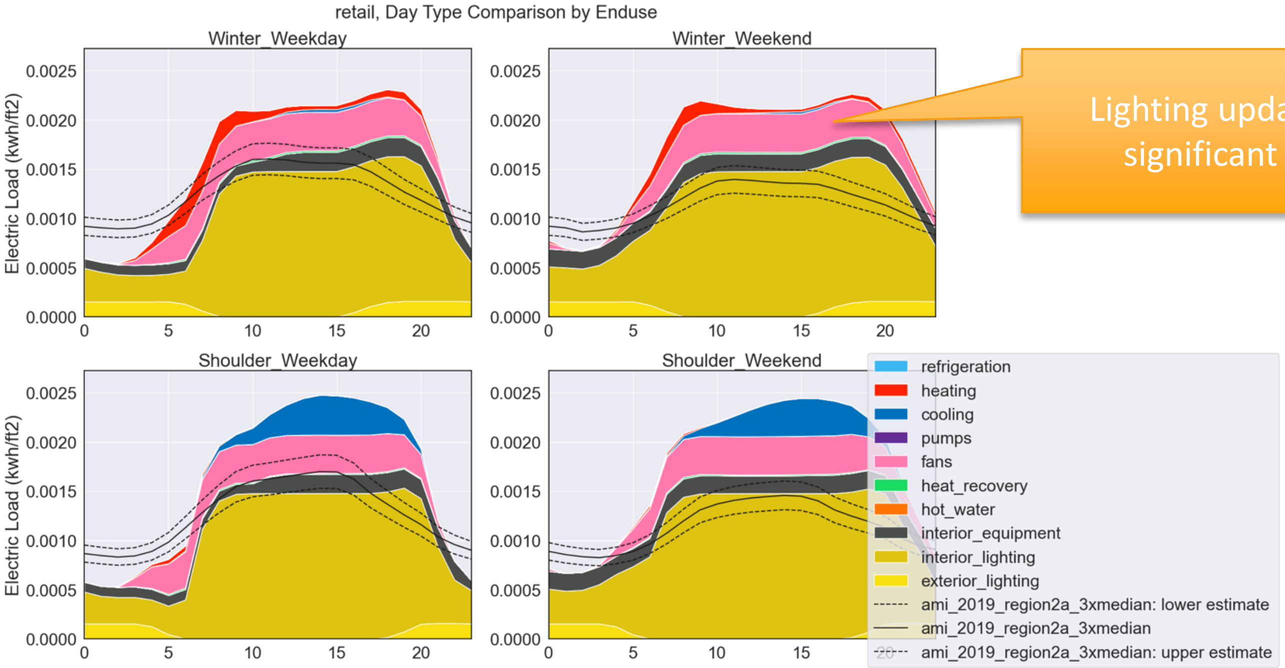
Nighttime setbacks could be causing the issue with low baseload. In the daytime, ComStock is still showing the bimodal peaks. This seems to be caused by the lighting schedules.

Retail – 1 Fort Collins



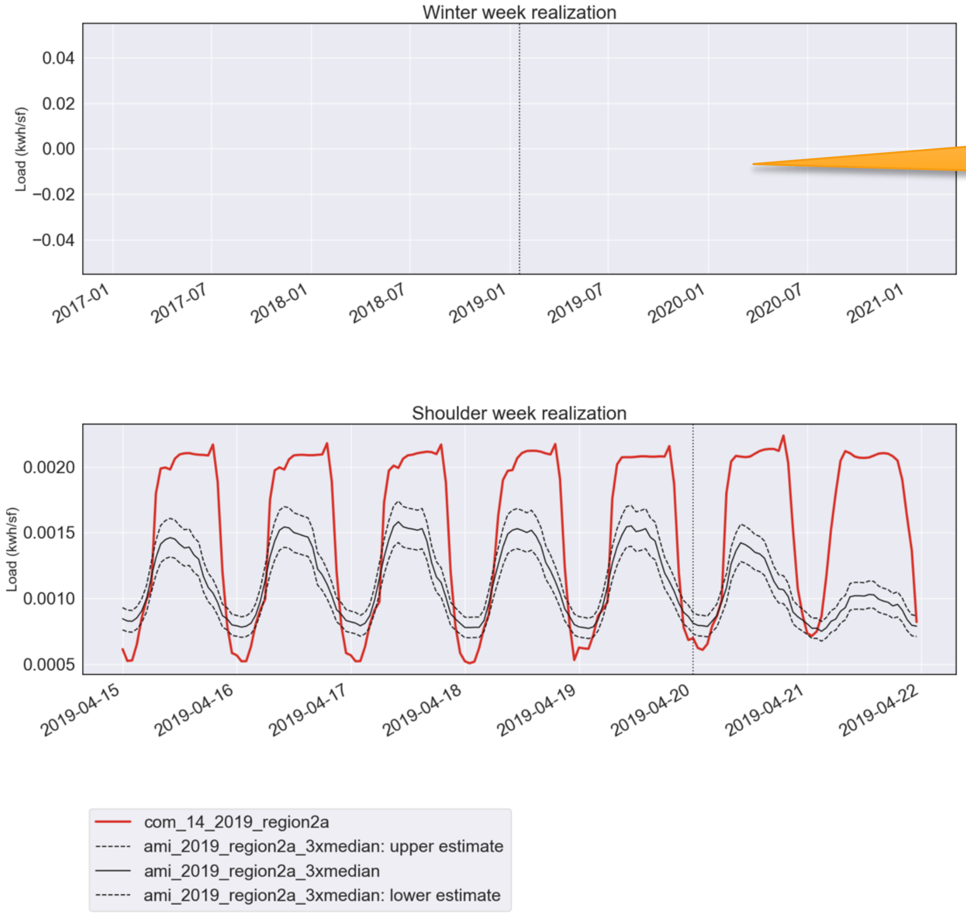
ComStock closer to AMI on peak days with higher load

Retail – 2a Seattle



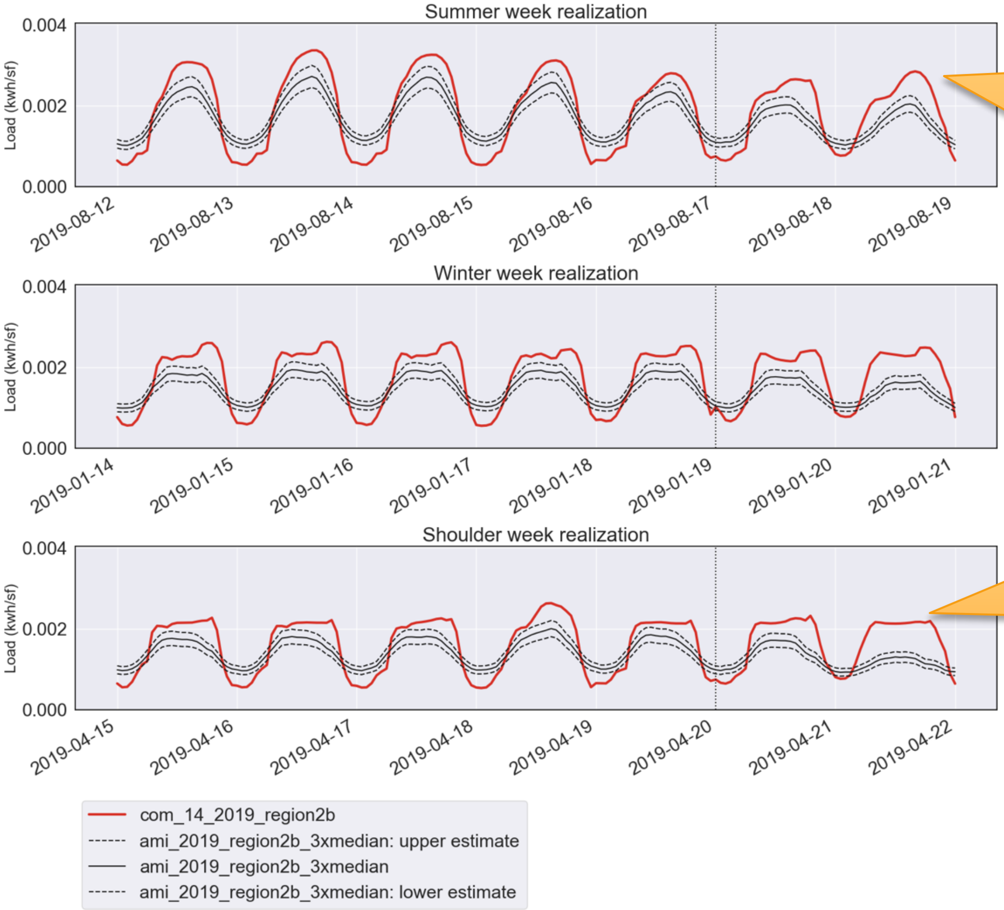
Lighting update should make significant improvement

Retail – 2a Seattle



No Seattle AMI for Retail during this week b/c of meter outages

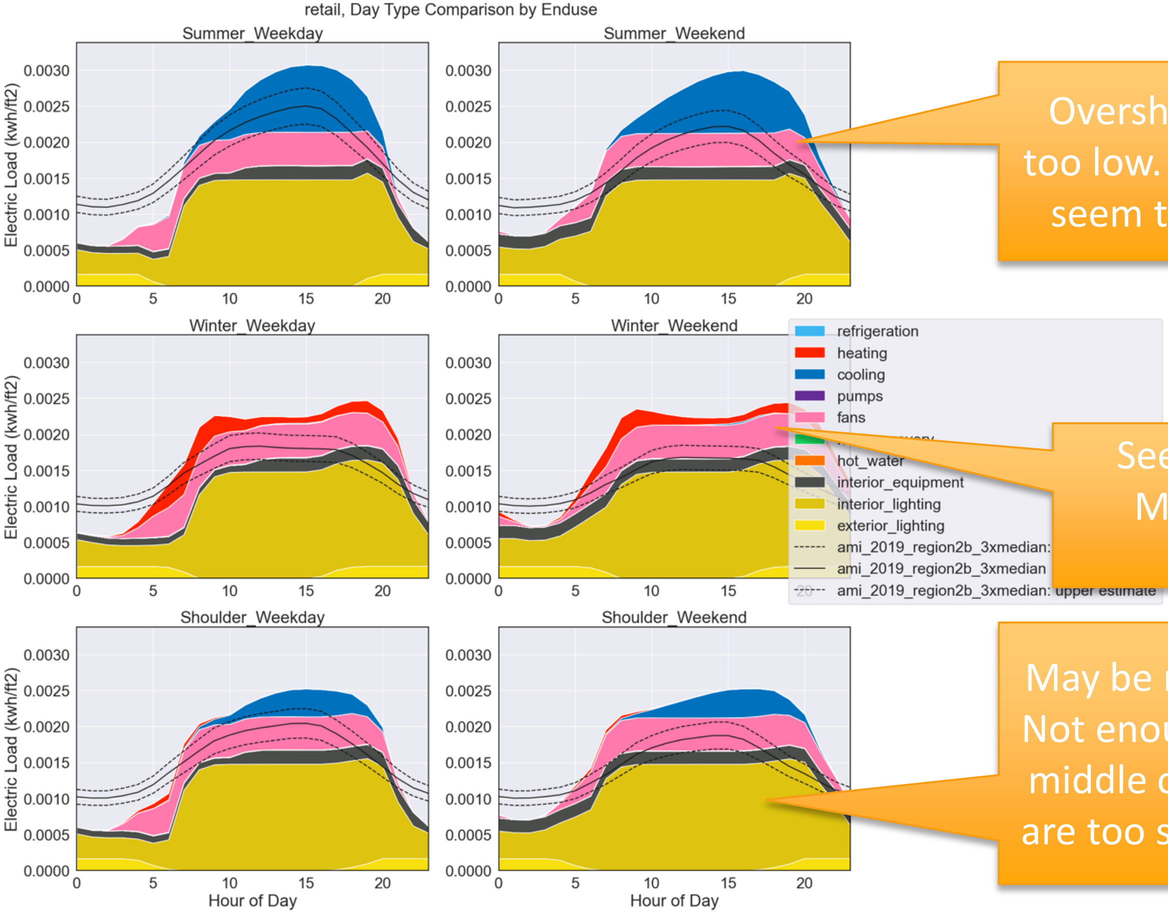
Retail – 2B Portland



Overshooting all days and missing some baseload. Model weekends show afternoon bump, that we don't see in Region 1 models or AMI data.

Seeing flat shape on most days, which AMI data does not support. We are especially overestimating on the weekends. Might be missing cooling end use?

Retail – 2B Portland



Overshooting and baseloads are too low. Weekend operating hours seem too long (esp. in evening).

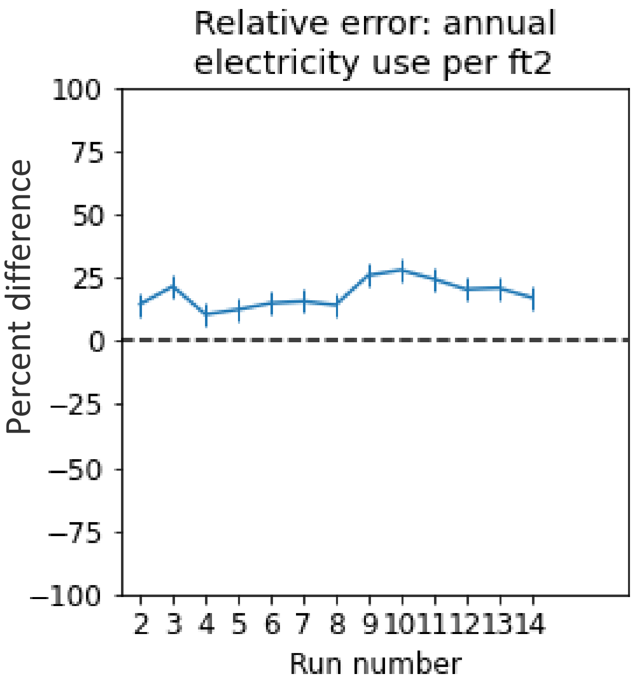
Seems like lighting is the culprit. May need more buildings that shutoff earlier

May be missing cooling from shoulder. Not enough base load, overshooting in middle of the day. Hours of operation are too square, check sch. distribution.

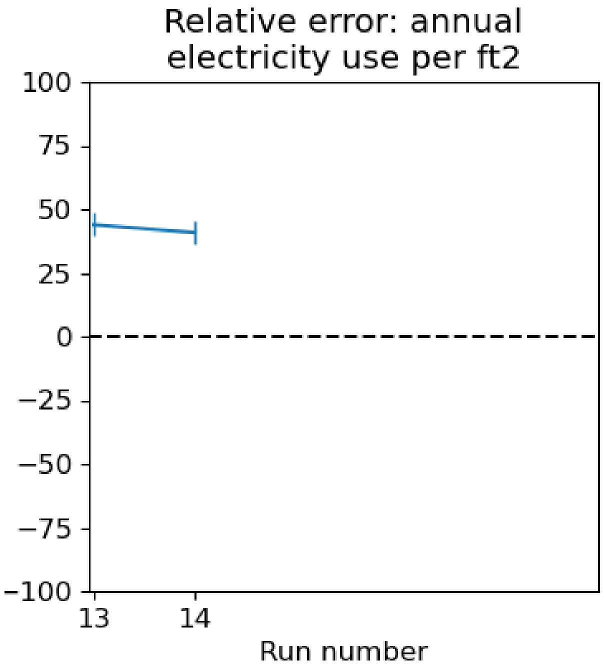
Tracking Quantities of Interest

All Regions: Annual Error

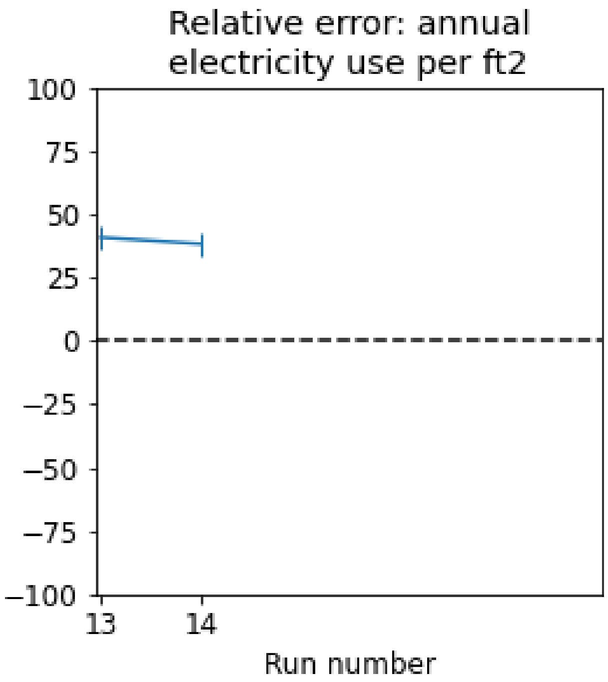
Region 1



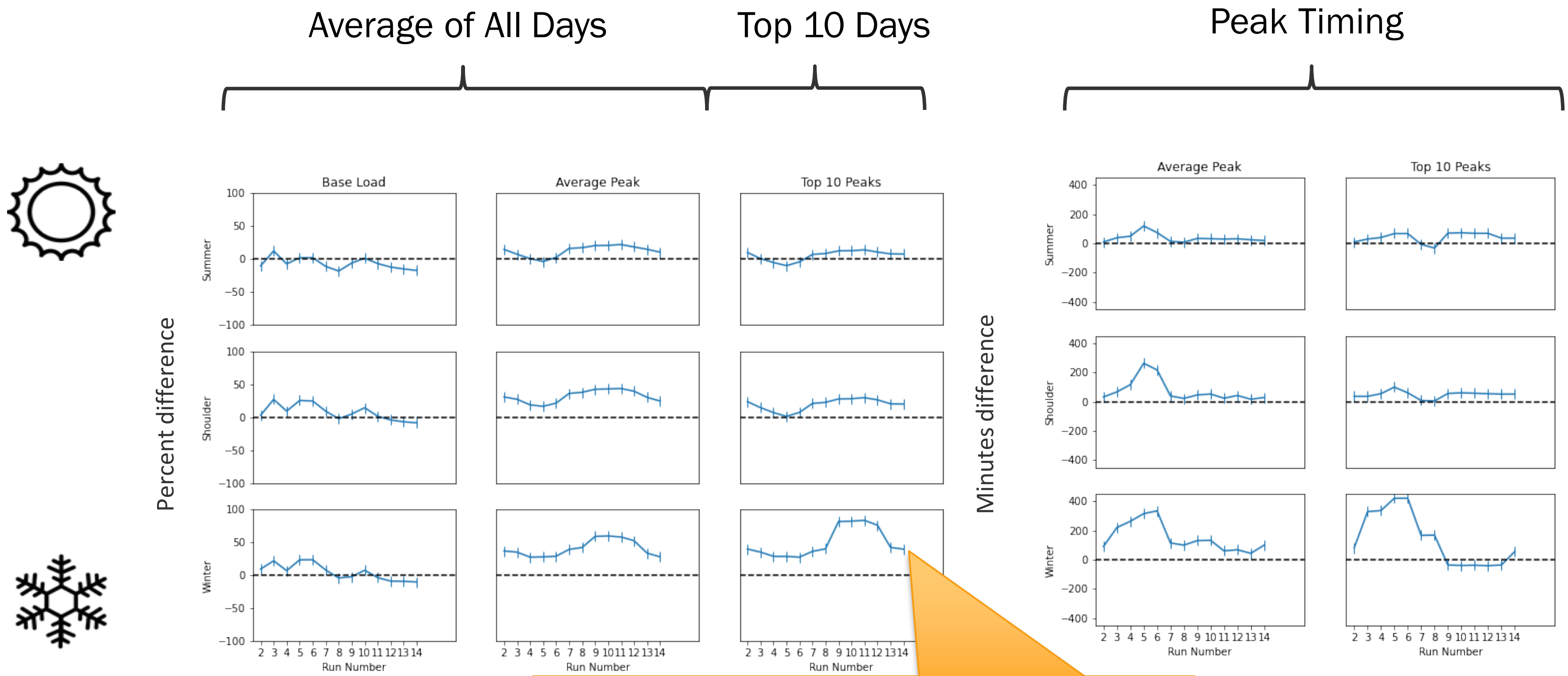
Region 2a



Region 2b

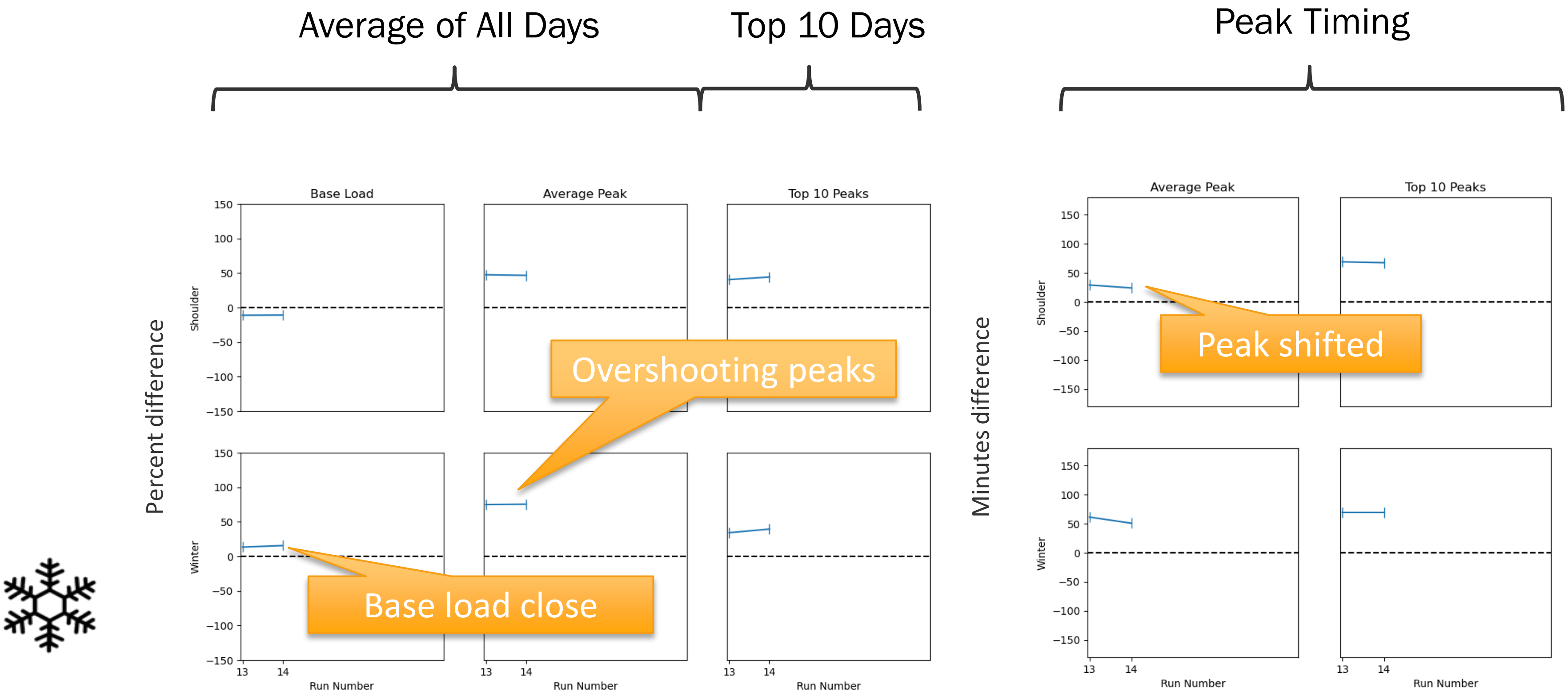


Region 1 Focus: Total Error Metrics



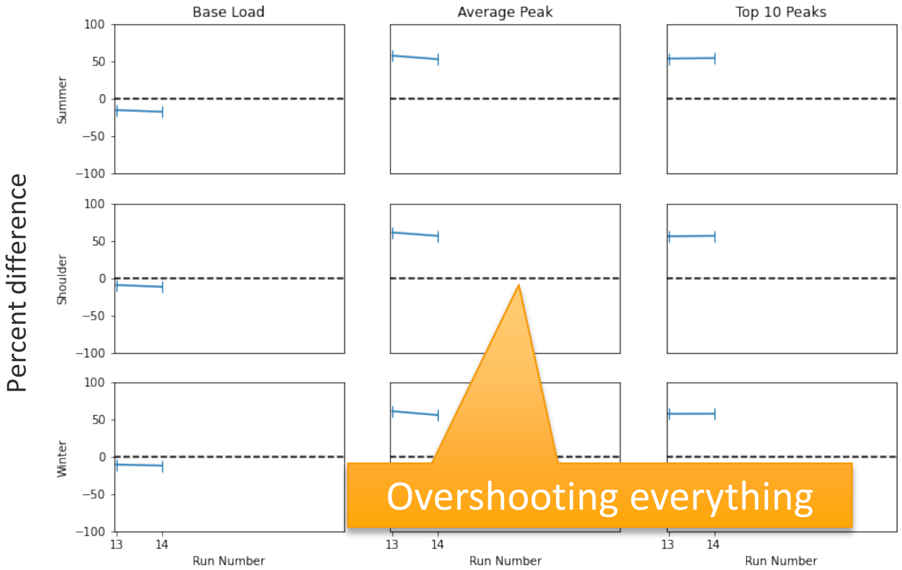
Overshooting winter & shoulder peaks

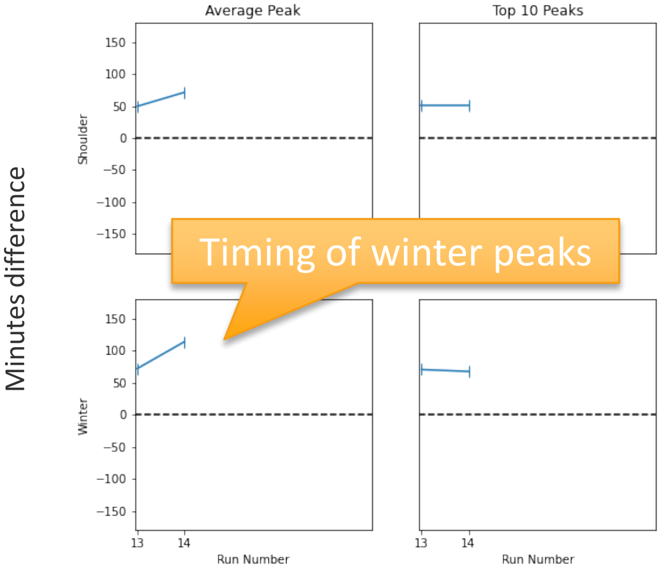
Region 2a Focus: Total Error Metrics



Region 2b Focus: Total Error Metrics

Average of All Days | Top 10 Days | Peak Timing





Areas for Improvement

Next Steps: Model Improvements

- Adjust space type ratios to create building subtypes (e.g., different kinds of warehouse buildings)
- Adjust lighting power density by updating energy code adoption and technology rollover by state/year
- Review distributions of schedule start & duration by building types
- Review datasets of HVAC nighttime operation, especially RTUs
- Continue emphasis on building types with biggest area/energy

Conclusions

- Spent much time and effort of misclassification/outliers
    - Used monthly Xcel Energy data from 500,000 meters spanning 8 states (presented in detail at TAG meeting)
    - Was necessary to get improve ground-truth data for calibration
- Ran 4 iterations of ComStock incorporating 4 discrete changes (2 before getting Region 2 data)
    - Saw general improvements in QOI metrics, but still overpredicting in Region 2
    - Most of the improvements made will carry over to the entire U.S.
- New/Updated visualizations
    - AMI data from Seattle City Light (aggregated by building type)
    - AMI data from Portland General Electric
- Priority areas for improvement for next region
    - Adjust lighting power density by updating energy code adoption and tech. rollover
    - Review distributions of schedule start & duration by building types
- Moving on to Region 3 (Vermont, Maine, and Cherryland, MI), but will continue tracking Region 1, 2a, 2b metrics

Questions for Breakout

First Impressions?

Given what we just showed, what are your gut reactions/impressions?

Will start at 11:15 Mountain Time

Seed Questions

1. Are we missing something obvious in thinking about the confidence in the AMI data?
    1. What confidence interval to use? HEMS/CEMS samples targeted 80% CI I believe.
2. Given the confidence ranges, does the idea to 0-1 normalize mean shapes make sense?
    1. Obviously need to pair this with comparison of EUI distributions to CBECS
3. ComStock is modeling ~70-80% of the commercial stock
    1. EIA data represents 100% of commercial sector
    2. Issues with commercial vs. industrial classification in reporting by utilities, per EIA team

4. Given these limitations on the quality of the truth data, do you recommend any changes to our approach to reporting, prioritizing, etc.?
5. If you had to choose, would you focus more on getting individual end-use shapes correct than on matching utility overall load shapes?
6. If you had to choose, would you focus more on buildings that represent most of the stock (retail, strip mall, warehouse) or spread focus more evenly across types?