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.
<table>
<thead>
<tr>
<th><strong>Today’s agenda</strong></th>
<th><strong>Mountain Time</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Welcome</td>
<td>10:00 - 10:05</td>
</tr>
<tr>
<td>Calibration progress summary</td>
<td>10:05 - 10:25</td>
</tr>
<tr>
<td>Residential calibration update</td>
<td>10:25 - 11:10</td>
</tr>
<tr>
<td>Breakout room 1: Deep dive on residential calibration Breakout room 2: Project recap</td>
<td>11:10 – 11:45</td>
</tr>
<tr>
<td>Break</td>
<td>11:45 – 11:50</td>
</tr>
<tr>
<td><strong>Breakout room 1:</strong> 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.</td>
<td>11:50 - 12:25</td>
</tr>
<tr>
<td>Breakout room 1: Building electrification load modeling panel Breakout room 2: Distributed PV Adoption Modeling with dGen</td>
<td>12:25 - 1:00</td>
</tr>
</tbody>
</table>
The novel approach delivers a nationally-comprehensive dataset at a fraction of the historical cost.
EE/DR savings profiles
Stochastic occupancy modeling capabilities
Technical Advisory Group
Rigorous calibration of building stock end-use models
Load profile library, documentation, & user guide
Ongoing additions to load profile library

Project Timeline

Year 1
- Define use cases and requirements
- Collect/review existing data
- Report on market needs and data gaps
- Targeted data acquisition leveraging planned/ongoing sub-metering studies
- Data analysis to derive occupant-driven schedules and usage diversity
- Rigorous calibration of building stock end-use models
- Quantify accuracy of results for target applications
- Stochastic occupancy modeling capabilities

Year 2
- Technical Advisory Group

Year 3
- Beyond

You are here
Com: 2 of 4 calibration regions complete
Res: 4 of 5 calibration regions complete

You are here
Com: 2 of 4 calibration regions complete
Res: 4 of 5 calibration regions complete
### Summary of FY21 Final Products for End-Use Load Profiles

<table>
<thead>
<tr>
<th>Published by 9/30/2021</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Public Datasets</strong></td>
</tr>
<tr>
<td>- VizStock Web Interface</td>
</tr>
<tr>
<td>- Pre-aggregated Load Profiles</td>
</tr>
<tr>
<td>- Raw Individual Building Load Profiles</td>
</tr>
<tr>
<td>- Raw Individual Building Models</td>
</tr>
<tr>
<td><strong>Dataset Access Instructions</strong></td>
</tr>
<tr>
<td>The project website will provide instructions on how to access and download the various dataset formats</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Completed by 9/30/2021</th>
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</thead>
<tbody>
<tr>
<td><strong>Webinar</strong></td>
</tr>
<tr>
<td>Conduct public outreach webinar to TAG and other stakeholders to present project outcomes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drafts to DOE &amp; TAG by 9/30/2021</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EERE or NREL report</strong></td>
</tr>
<tr>
<td><em>End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification</em></td>
</tr>
<tr>
<td>- Content: Detailed description of model improvements made for calibration; detailed explanation of validation and uncertainty of results</td>
</tr>
<tr>
<td>- Audience: Dataset and model users interested in technical details</td>
</tr>
<tr>
<td>- NREL lead; LBNL and ANL co-authors</td>
</tr>
<tr>
<td><strong>EERE or LBNL report</strong></td>
</tr>
<tr>
<td><em>End-Use Load Profiles for the U.S. Building Stock: Applications and Opportunities</em></td>
</tr>
<tr>
<td>- Content: Example applications and opportunities for using the dataset</td>
</tr>
<tr>
<td>- Audience: General users of datasets</td>
</tr>
<tr>
<td>- LBNL lead; NREL co-authors</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Final reports published by 12/31/2021</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

Published by 9/30/2021

Completed by 9/30/2021

Drafts to DOE & TAG by 9/30/2021

Final reports published by 12/31/2021
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
- N. Frick. 2019. End Use Load Profile Inventory

**Presentations and Slides**
- Technical Advisory Group slides
  - [LBNL](https://lbnl.gov) and [NREL](https://nrel.gov) site
- E. Wilson. 2020. EFX webinar
- E. Wilson. 2019. Peer Review presentation

**Software**
- OpenStudio Occupant Variability Gem and Non Routine Variability Gem (more info at [IBPSA newsletter](https://ibpsa-newsletter.org))

**Data**
- First year of 15-min NEEA HEMS data available: [https://neea.org/data/end-use-load-research/energy-metering-study-data](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!**
EE/DR savings profiles

Stochastic occupancy modeling capabilities

Technical Advisory Group

Rigorous calibration of building stock end-use models

Load profile library, documentation, & user guide

Data analysis to derive occupant-driven schedules and usage diversity

Calibrated building stock models

Targeted data acquisition leveraging planned/ongoing sub-metering studies

Quantify accuracy of results for target applications

Define use cases and requirements

Collect/review existing data

Report on market needs and data gaps

You are here

Com: 2 of 4 calibration regions complete
Res: 4 of 5 calibration regions complete

Project Timeline

FY19 (ends 9/30/2019)

FY20 (ends 9/30/2020)

FY21 (ends 9/30/2021)

Beyond

Ongoing additions to load profile library

Com: 2 of 4 calibration regions complete
Res: 4 of 5 calibration regions complete

You are here
Solution: A Hybrid Approach (2)

End-use data for sampled buildings

Whole-building/sector data from multiple regions

End-use profiles for sample

Aggregate AMI load profile for each building type in a region
Solution: A Hybrid Approach (2)

- Models calibrated to both end-use sample and AMI population data
- Validated at both the end use level and population level
Solution: A Hybrid Approach (2)

- 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

• We want to get the “why” right so we can ask questions about changes to the stock (i.e., savings load shapes)

• 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

• Calibrating outputs (true-up model) may be appropriate in some instances
Guiding Principles

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Guiding Principles

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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

- 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)

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
AMI data from Fort Collins municipal service territory (CO)
AMI data from ComEd service territory (IL)
EIA Form 861 electricity, natural gas data
EIA 861m modeled end-uses
EIA RECS modeled end-uses
Submeter end-uses
Utility load research data (LRD)
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

Background colors are DOE Building America Climate Regions

- Seattle City Light (completed under previous project)
- Fort Collins Utilities, CO
- ComEd
- EPB Chattanooga, TN
- Vermont (VEIC)
- Cherryland, MI
- Horry Electric Co-op
- MassRES1 Baseline Study
- FSEC PDR Metering
- NEEA RBSA Metering
- NEEA HEMS Metering
- Pecan St. Dataport
- LADWP (completed under previous project)
Commercial Calibration Dimensions

AMI data from (likely) Horry County, SC; Chattanooga 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)

EIA 861m electricity, natural gas

EIA CBECS

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

Annual gas and electricity EUIs by building type

Sub-metered end-uses

Sub-metered end-use load data

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

Region 1 AMI data

Region 2 AMI data

Region 3 AMI data

Region 4 AMI data
Summary of Commercial AMI Calibration Regions

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

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

Background colors are DOE Building America Climate 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,1 Janghyun Kim,1 Rajendra Adhikari,1 Anna C. McCreery,1 and Elizabeth Titus4

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.

Contact No. DE-AC36-08GO28308

https://www.nrel.gov/docs/fy20osti/77102.pdf
So how’s it going?
Residential Calibration

- Significant quantity of interest (QOI) improvements seen across four calibration focus regions, load research data, and EIA data comparisons

- Remaining areas of concern include electric heating and heating/cooling behavior during shoulder seasons

- Focusing on these for final region

- In parallel, developing true-up model to address behavior not captured by simulations

- Our research found that appliance, lighting, and plug load shapes are highly transferrable between regions

- But the magnitudes are not; we incorporated data on how these end uses vary by region

- Made many enhancements to the diversity and granularity of EULPs, which don’t show up in the main QOIs

- Region 5 of 5 to finish in July 2021
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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
  – Comparisons to EIA, CBECs, and Load Research Data will be important to add
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- Making model improvements in parallel, which have resulted in modest improvements in annual energy, peak magnitude, and peak timing
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- Including some enhancements to the diversity and granularity of EULPs, which don’t show up in the main QOIs
- 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
Advanced metering infrastructure (AMI) data from ComEd service territory (IL)

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
AMI data from Fort Collins municipal service territory (CO)

Residential Calibration Dimensions

EIA Form 861
EIA 861m electricity, natural gas data
EIA RECS modeled end-uses
Sub-meter end-uses
Utility load research data (LRD)

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.
Updated from 2012 to 2018

Adjusted for PV generation and billing periods
Summary of Residential AMI Calibration Regions

- Region 4:
  - Seattle City Light
  - Fort Collins Utilities, CO
  - ComEd
  - EPB Chattanooga, TN
  - Horry Electric Co-op
  - Tallahassee, FL

LADWP (completed under previous project)
Summary of Residential AMI Calibration Regions

- Seattle City Light
- Fort Collins Utilities, CO
- ComEd
- EPB Chattanooga, TN
- Cherryland, MI
- Horry Electric Co-op

Regions:
- Region 5 (current)
- Region 4

Utilities mentioned:
- LADWP (completed under previous project)
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

<table>
<thead>
<tr>
<th>Building Type RECS</th>
<th>Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Home</td>
<td>9.8%</td>
</tr>
<tr>
<td>Multi-Family with 2 - 4 Units</td>
<td>7.3%</td>
</tr>
<tr>
<td>Multi-Family with 5+ Units</td>
<td>10.0%</td>
</tr>
<tr>
<td>Single-Family Attached</td>
<td>2.3%</td>
</tr>
<tr>
<td>Single-Family Detached</td>
<td>70.7%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heating Fuel</th>
<th>Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>70.3%</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>0.2%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>22.2%</td>
</tr>
<tr>
<td>Other Fuel</td>
<td>1.8%</td>
</tr>
<tr>
<td>Propane</td>
<td>5.5%</td>
</tr>
</tbody>
</table>
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

<table>
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<th>Building Type RECS</th>
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<tbody>
<tr>
<td>Mobile Home</td>
<td>15.0%</td>
</tr>
<tr>
<td>Multi-Family with 2 - 4 Units</td>
<td>5.0%</td>
</tr>
<tr>
<td>Multi-Family with 5+ Units</td>
<td>18.0%</td>
</tr>
<tr>
<td>Single-Family Attached</td>
<td>4.5%</td>
</tr>
<tr>
<td>Single-Family Detached</td>
<td>57.4%</td>
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<table>
<thead>
<tr>
<th>Building Type RECS</th>
<th>Percent Vacant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Home</td>
<td>27.7%</td>
</tr>
<tr>
<td>Multi-Family with 2 - 4 Units</td>
<td>37.5%</td>
</tr>
<tr>
<td>Multi-Family with 5+ Units</td>
<td>66.4%</td>
</tr>
<tr>
<td>Single-Family Attached</td>
<td>38.9%</td>
</tr>
<tr>
<td>Single-Family Detached</td>
<td>20.6%</td>
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<table>
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<tr>
<th>Heating Fuel</th>
<th>Electricity</th>
<th>Fuel Oil</th>
<th>Natural Gas</th>
<th>None</th>
<th>Propane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation</td>
<td>94.5%</td>
<td>0.1%</td>
<td>3.0%</td>
<td>0.1%</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

Horry supplies both orange and blue shaded areas.
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

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</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>88.5%</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>0.2%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>8.2%</td>
</tr>
<tr>
<td>Other Fuel</td>
<td>0.2%</td>
</tr>
<tr>
<td>Propane</td>
<td>2.9%</td>
</tr>
</tbody>
</table>
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

res_national_48_2018
res_epb_scl_tal_48_2019

AMI/LRD uncertainty is 10%
AMI uncertainty is the standard error.
Seasonal end-use loads by day type

EPB, Chattanooga, TN service territory

Horry Electric service territory

City of Tallahassee service territory

res_national_48_2018
res_epb_scl_tal_48_2019

AMI/LRD uncertainty
AMI average

LRD uncertainty is 10%
AMI uncertainty is the standard error.
Seasonal end-use loads by day type

EPB, Chattanooga, TN service territory

Horry Electric service territory

City of Tallahassee service territory

---

AMI/LRD uncertainty
AMI average

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

Reasons for discrepancies

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

EPB, Chattanooga, TN

Relative error: annual electricity use per unit

Run number

<table>
<thead>
<tr>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>-20</td>
</tr>
<tr>
<td>-40</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
</tbody>
</table>

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

Horry Electric

Relative error: annual electricity use per unit

Run number

<table>
<thead>
<tr>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>-20</td>
</tr>
<tr>
<td>-40</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
</tbody>
</table>

QOIs calculated for previous 2018 runs

City of Tallahassee

Relative error: annual electricity use per unit

Run number

<table>
<thead>
<tr>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>-20</td>
</tr>
<tr>
<td>-40</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
</tbody>
</table>

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

Low on annual usage per unit

High on annual usage per unit
EPB, Chattanooga, TN service territory: shape error metrics

Average of All Days

Top 10 Days

Peak Timing

Summer peak timing could be improved
Horry Electric service territory: shape error metrics

Average of All Days

Top 10 Days

Peak Timing

Base Load
Region 2
Region 3
Region 4

Average Peak
Top 10 Peaks

Error (%) Summer

Error (%) Shoulder

Error (%) Winter

Run Number
15 20 25 30 35 40 45 50

Region 2
Region 3
Region 4

Average Peak
Top 10 Peaks

Error (min) Summer

Error (min) Shoulder

Error (min) Winter

Run Number
15 20 25 30 35 40 45 50

Summer peak could be improved

Shoulder baseload could be improved

Shoulder baseload could be improved
City of Tallahassee service territory: shape error metrics

- **Average of All Days**
  - **Base Load**
  - **Average Peak**
  - **Top 10 Peaks**

- **Top 10 Days**

- **Peak Timing**
  - **Average Peak**
  - **Top 10 Peaks**

*Winter peaks could be improved*
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

Time shift in some LRD sets
2018 Load Research Data Comparisons

Inaccurate customer counts affect comparison.
Inaccurate customer counts affect comparison
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

Significant increase in load especially in summer

Calibration target EIA Electric Sales Plus PV

Most states do not have significant PV generation

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

**Before weighting function applied**

**After weighting function applied**

- CA most likely uses billing months
- Summer peak shifted
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

Residential monthly EIA electricity adjusted billing reporting periods
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

res_national_48_2018
res_epb_scl_tal_48_2019

AMI/LRD uncertainty
AMI average

LRD uncertainty is 10%
AMI uncertainty is the standard error.
Seasonal end-use loads by day type

ComEd service territory

City of Fort Collins service territory

Seattle City Light service territory

AMI/LRD uncertainty
AMI average

LRD uncertainty is 10%
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res_national_48_2018
res_epb_scl_tal_48_2019
Seasonal end-use loads by day type

ComEd service territory

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Seattle City Light service territory

res_national_48_2018
res_epb_scl_tal_48_2019

--- AMI/LRD uncertainty
--- AMI average

LRD uncertainty is 10%
AMI uncertainty is the standard error.
Tracking Quantities of Interest
Annual error: previous calibration regions

**Reasons**
- Fort Collins and Seattle: Electric heating load too high
- ComEd: Low evening and early morning load
ComEd service territory: shape error metrics

Average of All Days
Top 10 Days

Peak Timing

Regional plug load multiplier made ComEd baseload worse

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

Average of All Days

<table>
<thead>
<tr>
<th>Base Load</th>
<th>Average Peak</th>
<th>Top 10 Peaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>R3</td>
<td>R4</td>
</tr>
</tbody>
</table>

Winter peaks

Winter peaks are too high

Roughly equal peaks causing timing issue

R2 = calibration region 2
R3 = calibration region 3
R4 = calibration region 4
Seattle City Light service territory: shape error metrics

### Average of All Days

- **Base Load**: 
  - Error (%): R3, R4
  - X-axis: Summer, Shoulder
  - Y-axis: -200 to 200

- **Average Peak**: 
  - X-axis: Run Number
  - Y-axis: -200 to 200

- **Top 10 Peaks**: 
  - X-axis: Run Number
  - Y-axis: -200 to 200

### Top 10 Days

- **Peak Timing**
  - **Average Peak**: 
    - X-axis: Run Number
    - Y-axis: -200 to 200
  - **Top 10 Peaks**: 
    - X-axis: Run Number
    - Y-axis: -200 to 200

R3 = calibration region 3
R4 = calibration region 4

**Winter peak timing could be improved**
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

Manhattan sleeps ~30 min later

Manhattan stays out ~1-1.5 hours later
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

* 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)

EPB, Chattanooga, TN  Horry Electric  City of Tallahassee

After baseload shifts
Before change
AMI uncertainty (standard error)
AMI average

Little impact due to most shifts being less than 30 min
Minor shape improvements
HVAC Updates
Update: Vacant Unit Heating Setpoints

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

**New Assumption**
- 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

- Decrease in all regions

- Largest difference in Horry

- Red lines: Reduced vacant unit setpoints
- Orange lines: Baseline
- Dark grey dash lines: AMI uncertainty (standard error)
- Medium grey line: AMI average
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/51k8o dysyf5hmpd6g9swr7g6y0cvxsv](https://nwcouncil.app.box.com/s/51k8o dysyf5hmpd6g9swr7g6y0cvxsv)
We found that RECS 2009 data on heating setpoints for zonal electric heating are lower on average than ducted electric furnaces/heat pumps.

<table>
<thead>
<tr>
<th>IECC Climate Zone</th>
<th>% of electric heat that is zonal</th>
<th>Avg. heating temp. when home</th>
<th>Avg. heating temp. at night</th>
<th>Avg. heating temp. when gone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td>Difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zonal electric</td>
<td>All others</td>
<td>Zonal electric</td>
</tr>
<tr>
<td>1A-2A</td>
<td>10%</td>
<td>71.5</td>
<td>69.7</td>
<td>71.6</td>
</tr>
<tr>
<td>2B</td>
<td>10%</td>
<td>71.3</td>
<td>73.7</td>
<td>71.1</td>
</tr>
<tr>
<td>3A</td>
<td>8%</td>
<td>71.1</td>
<td>71.3</td>
<td>71.0</td>
</tr>
<tr>
<td>3B-4B</td>
<td>31%</td>
<td>69.7</td>
<td>67.3</td>
<td>70.0</td>
</tr>
<tr>
<td>3C</td>
<td>55%</td>
<td>66.7</td>
<td>65.8</td>
<td>66.8</td>
</tr>
<tr>
<td>4A</td>
<td>20%</td>
<td>69.8</td>
<td>68.5</td>
<td>69.9</td>
</tr>
<tr>
<td>4C</td>
<td>64%</td>
<td>67.3</td>
<td>65.9</td>
<td>68.3</td>
</tr>
<tr>
<td>5A</td>
<td>54%</td>
<td>68.9</td>
<td>68.2</td>
<td>68.9</td>
</tr>
<tr>
<td>5B-5C</td>
<td>34%</td>
<td>69.0</td>
<td>67.0</td>
<td>69.1</td>
</tr>
<tr>
<td>6A-6B</td>
<td>52%</td>
<td>68.8</td>
<td>68.6</td>
<td>68.8</td>
</tr>
</tbody>
</table>

2A, 3A, and 4A are the IECC climate zones corresponding to Tallahassee, Horry, and Chattanooga.
We added a dependency on zonal electric heating to our heating setpoint and setback distributions queried from RECS 2009.

<table>
<thead>
<tr>
<th>Status</th>
<th>Zone 2004</th>
<th>Type RECS</th>
<th>HVAC Has Electric</th>
<th>Option 55°F</th>
<th>Option 60°F</th>
<th>Option 62°F</th>
<th>Option 65°F</th>
<th>Option 67°F</th>
<th>Option 68°F</th>
<th>Option 70°F</th>
<th>Option 72°F</th>
<th>Option 75°F</th>
<th>Option 76°F</th>
<th>Option 78°F</th>
<th>Option 80°F</th>
<th>sample_weight</th>
<th>sample_count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupied</td>
<td>2A</td>
<td>Single-Famili-No</td>
<td>No</td>
<td>0%</td>
<td>2%</td>
<td>1%</td>
<td>5%</td>
<td>3%</td>
<td>20%</td>
<td>23%</td>
<td>17%</td>
<td>15%</td>
<td>5%</td>
<td>7%</td>
<td>1%</td>
<td>9527435.45</td>
<td>1090</td>
</tr>
<tr>
<td>Occupied</td>
<td>3A</td>
<td>Single-Famili-No</td>
<td>No</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
<td>7%</td>
<td>3%</td>
<td>24%</td>
<td>22%</td>
<td>17%</td>
<td>13%</td>
<td>4%</td>
<td>6%</td>
<td>2%</td>
<td>10269769.4</td>
<td>901</td>
</tr>
<tr>
<td>Occupied</td>
<td>4A</td>
<td>Single-Famili-No</td>
<td>No</td>
<td>0%</td>
<td>2%</td>
<td>2%</td>
<td>8%</td>
<td>6%</td>
<td>28%</td>
<td>24%</td>
<td>19%</td>
<td>8%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>15959650.5</td>
<td>1716</td>
</tr>
<tr>
<td>Occupied</td>
<td>2A</td>
<td>Single-Famili-Yes</td>
<td>Yes</td>
<td>0%</td>
<td>16%</td>
<td>0%</td>
<td>13%</td>
<td>0%</td>
<td>12%</td>
<td>31%</td>
<td>7%</td>
<td>15%</td>
<td>1%</td>
<td>5%</td>
<td>1%</td>
<td>722695.87</td>
<td>77</td>
</tr>
<tr>
<td>Occupied</td>
<td>3A</td>
<td>Single-Famili-Yes</td>
<td>Yes</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
<td>9%</td>
<td>0%</td>
<td>7%</td>
<td>33%</td>
<td>23%</td>
<td>14%</td>
<td>2%</td>
<td>6%</td>
<td>4%</td>
<td>369640.28</td>
<td>31</td>
</tr>
<tr>
<td>Occupied</td>
<td>4A</td>
<td>Single-Famili-Yes</td>
<td>Yes</td>
<td>0%</td>
<td>8%</td>
<td>0%</td>
<td>15%</td>
<td>1%</td>
<td>28%</td>
<td>25%</td>
<td>3%</td>
<td>13%</td>
<td>3%</td>
<td>0%</td>
<td>3%</td>
<td>882617.64</td>
<td>84</td>
</tr>
</tbody>
</table>

Base at-home heating setpoint distribution

![Map of the United States with climate zones](image)
Impact: Zonal Baseboard Heating Setpoints

Some locations are slightly worse, but minor impact

- Total Stock
  - EPB, Chattanooga, TN
  - Horry Electric
  - Tallahassee, FL

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

<table>
<thead>
<tr>
<th>Main HVAC System Cooling Type</th>
<th>&lt;70F</th>
<th>70F-73F</th>
<th>74F-76F</th>
<th>77F-80F</th>
<th>&gt;80F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central AC</td>
<td>8.0%</td>
<td>19.0%</td>
<td>25.5%</td>
<td>36.4%</td>
<td>11.1%</td>
</tr>
<tr>
<td>Evaporative Cooler</td>
<td>13.2%</td>
<td>16.5%</td>
<td>25.9%</td>
<td>35.1%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Heat Pump</td>
<td>11.6%</td>
<td>29.2%</td>
<td>20.4%</td>
<td>33.4%</td>
<td>5.4%</td>
</tr>
<tr>
<td>Room AC</td>
<td>41.4%</td>
<td>53.0%</td>
<td>4.4%</td>
<td>1.3%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Non-room AC systems have approximately the same setpoints

Room AC setpoints ~6F cooler than other systems

Integrating lower room AC setpoints in ResStock

ResStock now accounts for lower room AC setpoints

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

Room AC setpoints ~6F cooler than other systems
Impact: Room AC Cooling Setpoints

- Total Stock
  - EPB, Chattanooga, TN
  - Horry Electric, SC
  - Tallahassee, FL
  - ComEd, IL
  - City of Fort Collins, CO
  - Seattle City Light, WA

**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
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
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, but prior calibration efforts focused on annual energy use.
The novel approach delivers a nationally-comprehensive dataset at a fraction of the historical cost.
Project Outcomes | Calibrated Building Stock Models

- 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

<table>
<thead>
<tr>
<th>Commercial</th>
<th>Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Small Office</td>
<td>• Single-Family Detached</td>
</tr>
<tr>
<td>• Medium Office</td>
<td>• Single-Family Attached</td>
</tr>
<tr>
<td>• Large Office</td>
<td>• Multifamily low-rise</td>
</tr>
<tr>
<td>• Stand-alone Retail</td>
<td>• Multifamily mid-rise</td>
</tr>
<tr>
<td>• Strip Mall</td>
<td>• Multifamily high-rise</td>
</tr>
<tr>
<td>• Primary School</td>
<td></td>
</tr>
<tr>
<td>• Secondary School</td>
<td></td>
</tr>
<tr>
<td>• Outpatient Healthcare</td>
<td></td>
</tr>
<tr>
<td>• Hospital</td>
<td></td>
</tr>
<tr>
<td>• Small Hotel</td>
<td></td>
</tr>
<tr>
<td>• Large Hotel</td>
<td></td>
</tr>
<tr>
<td>• Warehouse (non-ref.)</td>
<td></td>
</tr>
<tr>
<td>• Quick Service Restaurant</td>
<td></td>
</tr>
<tr>
<td>• Full Service Restaurant</td>
<td></td>
</tr>
<tr>
<td>• Supermarket</td>
<td></td>
</tr>
</tbody>
</table>
Example aggregate versus individual EULP concept demonstration using water draws
In-kind participation by 65 advisory group members
Technical Advisory Group

- Define use cases and requirements
- Collect/review existing data
- Report on market needs and data gaps
- Targeted data acquisition leveraging planned/ongoing sub-metering studies
- Data analysis to derive occupant-driven schedules and usage diversity
- Rigorous calibration of building stock end-use models
- Quantify accuracy of results for target applications

Load profile library, documentation, & user guide

EE/DR savings profiles

Ongoing additions to load profile library

**You are here**

Com: 2 of 4 calibration regions complete
Res: 4 of 5 calibration regions complete

**Project Timeline**

<table>
<thead>
<tr>
<th>FY19 (ends 9/30/2019)</th>
<th>FY20 (ends 9/30/2020)</th>
<th>FY21 (ends 9/30/2021)</th>
<th>Beyond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stochastic occupancy modeling capabilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rigorous calibration of building stock end-use models</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data analysis to derive occupant-driven schedules and usage diversity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Targeted data acquisition leveraging planned/ongoing sub-metering studies</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collect/review existing data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Define use cases and requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Report on market needs and data gaps</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FY19 (ends 9/30/2019)**

- Ongoing additions to load profile library

**FY20 (ends 9/30/2020)**

- Calibrated building stock models

**FY21 (ends 9/30/2021)**

- You are here

**Beyond**

- You are here

**Ends 9/30/2020**

**Ends 9/30/2021**
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
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
<table>
<thead>
<tr>
<th>Use Case</th>
<th>Time Resolution</th>
<th>Geographic Resolution</th>
<th>Electrical Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Resource Planning</td>
<td>Hourly or peak day</td>
<td>Service territory</td>
<td>Real power</td>
</tr>
<tr>
<td>Energy Efficiency Planning</td>
<td>Hourly or peak day</td>
<td>Service territory</td>
<td>Real power</td>
</tr>
<tr>
<td>Policy and Rate Design</td>
<td>15 min to hourly</td>
<td>City, climate zone, or state</td>
<td>Depends on application</td>
</tr>
<tr>
<td>Transmission and Distribution System Planning</td>
<td>15 min or smaller</td>
<td>Distribution feeder</td>
<td>Real and reactive power</td>
</tr>
<tr>
<td>Program Impact Evaluation</td>
<td>Hourly</td>
<td>Service territory</td>
<td>Real power</td>
</tr>
<tr>
<td>Demand-Response Planning</td>
<td>15 min to hourly</td>
<td>Service territory</td>
<td>Real power</td>
</tr>
<tr>
<td>Improved Building Energy Modeling</td>
<td>15 min</td>
<td>Region</td>
<td>Real power</td>
</tr>
<tr>
<td>Electrification Planning</td>
<td>Hourly</td>
<td>Service territory or smaller</td>
<td>Real power</td>
</tr>
<tr>
<td>Emissions Analysis</td>
<td>Hourly</td>
<td>Service territory or larger</td>
<td>Real power</td>
</tr>
<tr>
<td>PV Planning</td>
<td>1 min</td>
<td>Weather station</td>
<td>Real power</td>
</tr>
</tbody>
</table>
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?

**Input Data**
(non-timeseries characteristics, weather)

**Timeseries Data**
(end-use, whole-building, sector)

**Comparison**
Extract schedules, diversity

**ComStock**
100,000s of virtual buildings

**ResStock**
Calibration feedback informs updates to inputs
## Model Calibration Data

### Summary of Calibration Data Classes

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

[Summary graph]

https://www.nrel.gov/docs/fy20osti/77102.pdf
## Sample Sizes: Weather-driven End Uses

<table>
<thead>
<tr>
<th>Weather-driven</th>
<th>Proposed Minimum Sample Size(^1)</th>
<th>Oct 31(^{st}) Package Sample Size(^2)</th>
<th>Procured Sample Size(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>48</td>
<td>6218</td>
<td>5176</td>
</tr>
<tr>
<td>Cooling</td>
<td>48</td>
<td>6598</td>
<td>5351</td>
</tr>
<tr>
<td>Fans</td>
<td>21</td>
<td>2497</td>
<td>328</td>
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<tr>
<td>Pumps</td>
<td>21</td>
<td>500</td>
<td>83</td>
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<td>Heat Rejection</td>
<td>21</td>
<td>21</td>
<td>41</td>
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<tr>
<td>Humidification</td>
<td>21</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td>Heat Recovery</td>
<td>21</td>
<td>22</td>
<td>36</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>21</td>
<td>1076</td>
<td>1010</td>
</tr>
<tr>
<td>Exterior Lighting</td>
<td>21</td>
<td>846</td>
<td>846</td>
</tr>
</tbody>
</table>

\(^1\)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

<table>
<thead>
<tr>
<th>Schedule-driven</th>
<th>Hospital</th>
<th>Outpatient</th>
<th>Primary School</th>
<th>Secondary School</th>
<th>Full-Service Restaurant</th>
<th>Quick Service Restaurant</th>
<th>Retail</th>
<th>Strip Mall</th>
<th>Supermarket</th>
<th>Small Hotel</th>
<th>Large Hotel</th>
<th>Warehouse</th>
<th>Multifamily</th>
<th>Small Office</th>
<th>Medium Office</th>
<th>Large Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Minimum Sample Size&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior Lighting</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
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<tr>
<td>Interior Equipment</td>
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<td>21</td>
<td>21</td>
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<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<td>n/a</td>
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<tr>
<td>Oct 31&lt;sup&gt;st&lt;/sup&gt; Package Sample Size&lt;sup&gt;2&lt;/sup&gt;</td>
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<td>106</td>
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<td>Cooking</td>
<td>0</td>
<td>2</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Interior Lighting</td>
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<td>162</td>
<td>710</td>
<td>800</td>
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<td>131</td>
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</tr>
<tr>
<td>Interior Equipment</td>
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<td>200</td>
<td>196</td>
<td>3</td>
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<td>53</td>
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</tr>
<tr>
<td>Service Water Heating</td>
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<td>0</td>
<td>317</td>
<td>107</td>
<td>1</td>
<td>0</td>
<td>15</td>
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<tr>
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<td>0</td>
<td>2620</td>
<td>1</td>
<td>1</td>
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</tr>
</tbody>
</table>

---

<sup>1</sup>Minimum sample size targets presented at subject matter expert webinar on 8/28/2019.

<sup>2</sup>Counts based on vendor rough estimates obtained during market outreach.

<sup>3</sup>Procured Sample Size includes data in hand and data that is being contracted for procurement.
Commercial Calibration Dimensions

AMI data from (likely) Horry County, SC; Chattanooga, 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)

EIA 861m electricity, natural gas
EIA CBECs
Submetered end-uses
Utility load research data (LRD)

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.
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
- AMI data from Fort Collins municipal service territory (CO)

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

EIA Form 861
EIA 861m electricity, natural gas data
EIA RECS modeled end-uses
Submeter end-uses
Utility load research data (LRD)

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)

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

Housing Characteristic Importance (Total Site Electricity)

Model Info:
Type = RandomForest
n_estimators = 400
Model accuracy:
Test Accuracy = 93%

Legend:
saturation inputs
continuous inputs
Uncertainty Quantification (UQ)

Without UQ
- Percent of homes with AC: 50% (in specific county/vintage)
- Other inputs
- Run Model
- Peak = 4 MW

With UQ
- Percent of homes with AC: 40%, 43%, 50%, 56%, 59%
- Other inputs
- Run Model
- Peak = 3.7–4.2 MW

The uncertainty range is propagated through the model to determine uncertainty of outputs.
Residential end-use transferability study
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

Enduse Load Profile Comparison: dishwasher

Enduse Load Profile Comparison: clothes_washer

Enduse Load Profile Comparison: cooking_range

Enduse Load Profile Comparison: clothes_dryer
New Residential Stochastic Occupant Behavior Model
# Summary of Changes

<table>
<thead>
<tr>
<th>Activity</th>
<th>2019 Status</th>
<th>March 2020 Status</th>
<th>Type</th>
<th>Data sources</th>
<th>Magnitude (Power, Flow)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Schedule</td>
<td>Schedule</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heterogeneity</td>
<td>Stochasticity</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>Occupant (heat gain)</td>
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<td>No</td>
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<td>Yes</td>
<td>Occupants</td>
</tr>
<tr>
<td>SinksHW</td>
<td>Yes*</td>
<td>Yes*</td>
<td>Yes</td>
<td>Yes</td>
<td>Household</td>
</tr>
<tr>
<td>Showers/Baths HW</td>
<td>Yes*</td>
<td>Yes*</td>
<td>Yes</td>
<td>Yes</td>
<td>Occupants</td>
</tr>
<tr>
<td>Dishwasher HW</td>
<td>Yes*</td>
<td>Yes*</td>
<td>Yes</td>
<td>Yes</td>
<td>Occupants</td>
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<td>Dishwasher kW</td>
<td>Yes*</td>
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<td>Yes</td>
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<td>Occupants</td>
</tr>
<tr>
<td>Clothes Washer HW</td>
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</tr>
<tr>
<td>Clothes Dryer kW</td>
<td>Yes*</td>
<td>Yes*</td>
<td>Yes</td>
<td>Yes</td>
<td>Occupants</td>
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<td>Cooking Range</td>
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<td>No</td>
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<td>Misc. Electric Loads</td>
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<td>Yes</td>
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</tr>
<tr>
<td>Lighting</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Thermostat setpoints</td>
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<td>Bath exhaust fan</td>
<td>No</td>
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<td>Yes</td>
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<td>Household</td>
</tr>
<tr>
<td>Kitchen exhaust fan</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Household</td>
</tr>
</tbody>
</table>

* = 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.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Sunday</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
</tr>
</thead>
</table>

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

www.nrel.gov

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.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Mountain Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welcome</td>
<td>10:00 - 10:05</td>
</tr>
<tr>
<td>Data publication plan overview</td>
<td>10:05 - 10:25</td>
</tr>
<tr>
<td>Commercial calibration update</td>
<td>10:25 - 11:10</td>
</tr>
<tr>
<td>Breakout Room 1: Deep dive on commercial calibration</td>
<td>11:10 - 11:50</td>
</tr>
<tr>
<td>Breakout Room 2: Electric vehicle infrastructure projection and charging load profile tool</td>
<td></td>
</tr>
<tr>
<td>Plenary 3 - What’s next</td>
<td>11:50 - 12:25</td>
</tr>
<tr>
<td>Wrap up</td>
<td>12:25 - 12:30</td>
</tr>
</tbody>
</table>
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 present *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?
Same Data, Multiple Scales

Aggregates

Web Viewer

Individual Buildings

Real data will be spikier
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

- 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
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

<table>
<thead>
<tr>
<th>Month</th>
<th>Denver, CO</th>
<th>Boulder, CO</th>
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<tbody>
<tr>
<td>January</td>
<td>1995</td>
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<td>1981</td>
</tr>
<tr>
<td>April</td>
<td>1999</td>
<td>1986</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Residential Building Types</th>
<th>Residential End Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Family Detached</td>
<td>Heating</td>
</tr>
<tr>
<td>Single-Family Attached</td>
<td>Cooling</td>
</tr>
<tr>
<td>Multifamily 2–4 Units</td>
<td>Furnace/AC fan</td>
</tr>
<tr>
<td>Multifamily 5+ Units (1-3 stories)</td>
<td>Boiler pumps</td>
</tr>
<tr>
<td>Multifamily 5+ Units (4-7 stories)</td>
<td>Vent. fans</td>
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<tr>
<td>Multifamily 5+ Units (8+ stories)</td>
<td>Water heating</td>
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<tr>
<td></td>
<td>Interior Lights</td>
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<tr>
<td></td>
<td>Exterior Lights</td>
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<td>Misc. plug loads</td>
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<td>Refrigerator</td>
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<td>Clothes washer</td>
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<tr>
<td></td>
<td>Clothes dryer</td>
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<tr>
<td></td>
<td>Dishwasher</td>
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<tr>
<td></td>
<td>Cooking Range</td>
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<tr>
<td>Commercial Building Types</td>
<td>Commercial End Uses</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>------------------------</td>
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<tr>
<td>Small Office</td>
<td>Heating</td>
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<tr>
<td>Medium Office</td>
<td>Cooling</td>
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<td>Large Hotel</td>
<td>Heat Recovery</td>
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<td>Quick Service Restaurant</td>
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<td>Full Service Restaurant</td>
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## Commercial Building Characteristics

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<td>energy_code_when_envelope_last_updated</td>
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<td>energy_code_when_exterior_lighting_last_updated</td>
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<td>floor_to_floor_height</td>
<td>energy_code_when_hvac_last_updated</td>
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<td>party_wall_fraction</td>
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<td>party_wall_stories_north</td>
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<td>party_wall_stories_south</td>
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<td>energy_code_when_service_water_heating_last_updated</td>
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<td>weekend_operation_start_time</td>
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<td>weekend_operation_start_time</td>
<td></td>
</tr>
<tr>
<td>weekend_operation_duration</td>
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</table>
Commercial Calibration Update
Region 2 & Overall Status

Andrew Parker
Matthew Dahlhausen
April 22, 2021
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

AMI data from (likely) Horry County, SC; Chattanooga 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)

AM81m electricity, natural gas
EIA CBECs
Sub-metered end-uses
EAI electricity, natural gas consumption by state, sector
AM81m electricity, natural gas consumption by state, sector
Load duration curves and seasonal load shapes of ~16 utilities around U.S.

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

They were working out kinks in smaller customer AMI rollout; only larger customers reading

More short outages in smaller customer AMI system; remaining data from large customers only
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.
For calibration, drop data from timesteps where # buildings < 30%
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

In practice, filters are narrow and cover the outage periods exactly
Calibration Strategy
Model Architecture

Building stock characteristics database

Physics-based computer modeling

National
Climate/Region
State
County

Modeling Algorithms
Schedules
Human Behavior

Performance Curves
Component Properties
Weather Data
Calibration Process for One Region

Focus on reducing error for one region at a time

Keep an eye on impacts to other regions

Error

Region 1 Calibration | Region 2 Calibration | Region 3 Calibration | Region 4 Calibration | Region 5 Calibration

Before Calibration | After Calibration
Calibration Process Over Time

Focus on reducing error for one region at a time

Keep an eye on impacts to earlier regions
Calibration Process Over Time

Calibration efforts for earlier regions create better starting point for later regions.
Improvements from later regions will improve results for regions focused on earlier.
Summary of Commercial AMI Calibration Regions

Background colors are DOE Building America Climate Regions

Seattle City Light

Portland General Electric

Fort Collins Utilities, CO

LADWP (completed under previous project)

Vermont (VEIC)

Cherryland, MI

EPB Chattanooga, TN

Horry County, SC
Region 2 Focus: Major Schedules

Building stock characteristics database

Physics-based computer modeling

Exterior Lighting

HVAC Operation

National

Climate/Region

State

County

Modeling Algorithms

Schedules

Component Properties

Performance Curves

Human Behavior

Weather Data

Lighting schedules
Plug load schedules
Operation schedules
Region 2a – Seattle, WA

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

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<thead>
<tr>
<th>building_type</th>
<th>count</th>
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<tbody>
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<td>full_service_restaurant</td>
<td>167</td>
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<tr>
<td>hospital</td>
<td>12</td>
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<tr>
<td>large_hotel</td>
<td>39</td>
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<td>large_office</td>
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<td>outpatient</td>
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<tr>
<td>warehouse</td>
<td>633</td>
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</table>
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

<table>
<thead>
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<tbody>
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<td>full_service_restaurant</td>
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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

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

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

Modify BPR of existing schedules by changing the base load.
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 \textit{wkdy\_bpr} and \textit{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: \textit{wkdy\_bpr} modifies weekday schedules, and \textit{wknd\_bpr} modifies weekend schedules.
Impact: Lighting Base-to-Peak Variability

Before

After

Region 1 – Ft. Collins

Higher base load
Impact: Plug Load Base-to-Peak Variability

Before

After

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

Region 1 – Ft. Collins
# Update: Exterior Lighting Power Density

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<th>Considerations</th>
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<td>Exterior lighting power density</td>
<td>buildings where exterior lighting is defined</td>
<td>• Lighting power density in two sub-categories (parking and entry canopy) of exterior lighting are updated.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Based on 2015 U.S. Lighting Market Characterization report.</td>
</tr>
</tbody>
</table>
Various information from 2015 U.S. Lighting Market Characterization (LMC) report
For parking applications (about 50% of total exterior lighting nationally)

- Total # of Parking Lamps: 83,519,000 systems
- Avg Parking Light System Power: 216 W/system
- Avg Parking Lit Hours: 16 hrs/day
- Avg # of spots: 13 lot-spots/system, 2.5 garage-spots/system
- Total lot/garage spots:
  - Lot-spots/nationwide: 610,000,000
  - Garage-spots/nationwide: 85,000,000

Possible to derive,

\[
216 \text{ W/system} \div 13 \text{ lot-spots/system} = 16.615 \text{ W/lots-spots}
\]

\[
16.615 \text{ W/lots-spots} \div \frac{405 \text{ sqft/lot-spots}}{\text{405 sqft/lot-spots}} = 0.041 \text{ W/sqft (national average for parking lots only)}
\]

**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.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># of Buildings</td>
<td>85652</td>
<td>96278</td>
<td>98128</td>
<td>28707</td>
<td>41235</td>
</tr>
<tr>
<td>Portion</td>
<td>24%</td>
<td>28%</td>
<td>28%</td>
<td>8%</td>
<td>12%</td>
</tr>
<tr>
<td>Original LPD (W/ft²)</td>
<td>0.15</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0.18</td>
</tr>
<tr>
<td>Revised LPD (W/ft²)</td>
<td>0.045</td>
<td>0.045</td>
<td>0.030</td>
<td>0.030</td>
<td>0.055</td>
</tr>
</tbody>
</table>

LMC’s weighted average = 0.041 W/ft²
Update: Exterior Lighting Power Density

Before

After

Exterior lighting power reduction

Region 1 – Ft. Collins

Total – All Building Types
Update: Warehouse Operation Schedules

<table>
<thead>
<tr>
<th>Task</th>
<th>Affected Building Type</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse schedules (lighting, plug load, occupancy)</td>
<td>warehouse</td>
<td>• Operations of warehouses were reviewed and reconsidered in terms of day types between weekdays and weekends.</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Census Division</th>
<th>US State</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>EastNorthCentral</td>
<td>IL</td>
<td>2</td>
</tr>
<tr>
<td>MidAtlantic</td>
<td>PA</td>
<td>3</td>
</tr>
<tr>
<td>Mountain</td>
<td>CO</td>
<td>2</td>
</tr>
<tr>
<td>Pacific</td>
<td>CA</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>OR</td>
<td>1</td>
</tr>
<tr>
<td>SouthAtlantic</td>
<td>MD</td>
<td>1</td>
</tr>
<tr>
<td>WestSouthCentral</td>
<td>LA</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>TX</td>
<td>2</td>
</tr>
</tbody>
</table>
Update: Warehouse Operation Schedules

Region 2b - Portland

Overshot warehouse schedule correction; some still have weekend operation
HVAC Updates
## Update: HVAC Controls

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

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

"...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/ft² decrease (0.99 → 0.74 W/ft²) between 2014 and 2019
- ComStock values, in 2019, show a <0.1 W/ft² 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

Source: NEEA Commercial Building Stock Assessment 2019
Total Commercial Stock Status
Region 1 – Fort Collins

Overestimating in all seasons, but potentially not all for the same reason
Region 1 – Fort Collins

Need to review shape to understand main drivers
Maybe overestimating fan energy?
Region 2a – Seattle – Correction Since 2/28

- 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

Winter week realization

Shoulder week realization

- **com_14_2019_region2a**
- **ami_2019_region2a_3median: upper estimate**
- **ami_2019_region2a_3median**
- **ami_2019_region2a_3median: lower estimate**
Region 2a - Seattle

Suspect much of this error due to aggressive lighting technology changes in pacific northwest in last 10 years
Region 2b - Portland

Same as Seattle; likely overestimating lighting power density
Region 2b - Portland

Likely overestimating lighting power density
Region 2b - Portland

Total Day Type Comparison by Enduse

Summer_Weekday
Summer_Weekend
Winter_Weekday
Winter_Weekend
Shoulder_Weekday
Shoulder_Weekend

Electric Load (kW/h/M2)

Hour of Day

Enduse:
- refrigeration
- heating
- cooling
- pumps
- fans
- heat_recovery
- hot_water
- interior_equipment
- interior_lighting
- exterior_lighting

Data:
- ami_2019_region2b_3median: lower estimate
- ami_2019_region2b_3median: upper estimate
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
Lighting reduction will help, but not completely.
Warehouse – 2B Portland

Lighting power density reduction should help significantly

Overshot warehouse schedule correction; some still have weekend operation
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.
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.
Lighting reduction will help, but not completely. Need to look at HVAC operation as well.
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

Lighting reduction should help, but not entirely.

Need to investigate fan and HVAC operation schedules
Retail
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
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?
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

Relative error: annual electricity use per ft²

Region 2a

Relative error: annual electricity use per ft²

Region 2b

Relative error: annual electricity use per ft²
Region 1 Focus: Total Error Metrics

Average of All Days

Top 10 Days

Peak Timing

Overshooting winter & shoulder peaks
Region 2a Focus: Total Error Metrics

Average of All Days

Top 10 Days

Peak Timing

- Base load close
- Overshooting peaks
- Peak shifted
Region 2b Focus: Total Error Metrics

Average of All Days  Top 10 Days  Peak Timing

Percent difference

Minutes difference

Overshooting everything

Timing of winter peaks
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 CBECES

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?