Non-Intrusive Load Monitoring: Advances and Opportunities

Regional EM&V Forum Webinar
Monday, July 31st, 2017
12:30-2pm EST
www.neep.org

Northeast Energy Efficiency Partnerships

"Assisting the Northeast & Mid-Atlantic Region in Reducing Total Carbon Emissions 80% by 2050"

Mission

Accelerate energy efficiency as an essential part of demand-side solutions that enable a sustainable regional energy system

Vision

That the region embraces next generation energy efficiency as a core strategy to meet energy needs in a carbon-constrained world

Approach

Overcome barriers and transform markets through *Collaboration, Education, and Enterprise*

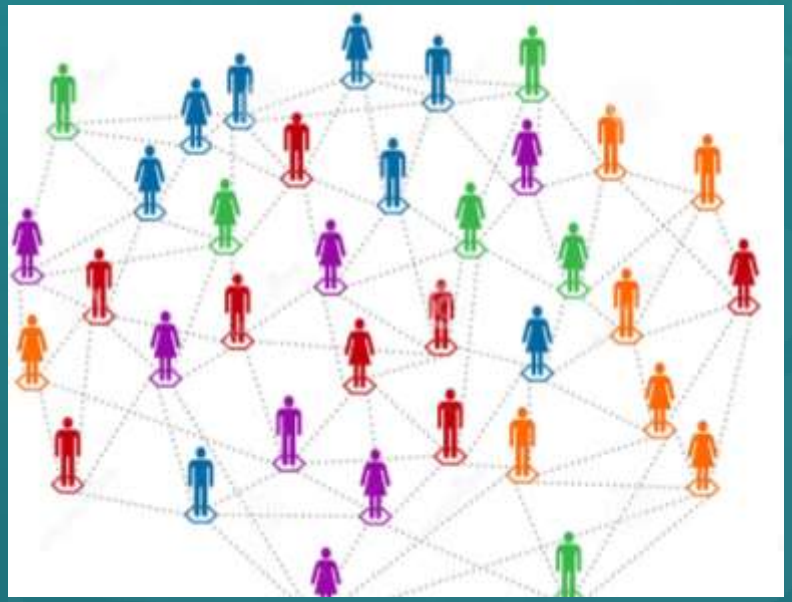
About NEEP

A Regional Energy Efficiency Organization

One of six REEOs funded in-part by U.S. DOE to support state and local efficiency policies and programs.

Regional EM&V Forum

Supports use and transparency of **best practices** in EM&V and reporting of **impacts** of energy efficiency and development of **strategies** and **tools** to meet evolving policy and program needs for efficiency.



- *NEEP AND ITS STATE PARTNERS ARE INVOLVED IN A PILOT STUDY COMPARING "M&V2.0" WITH TRADITIONAL METHODS*
- *NEEP IS BUILDING AN EM&V LEADERSHIP NETWORK*

NEEP's Next Generation Efficiency Strategic 2017-2019 Agenda

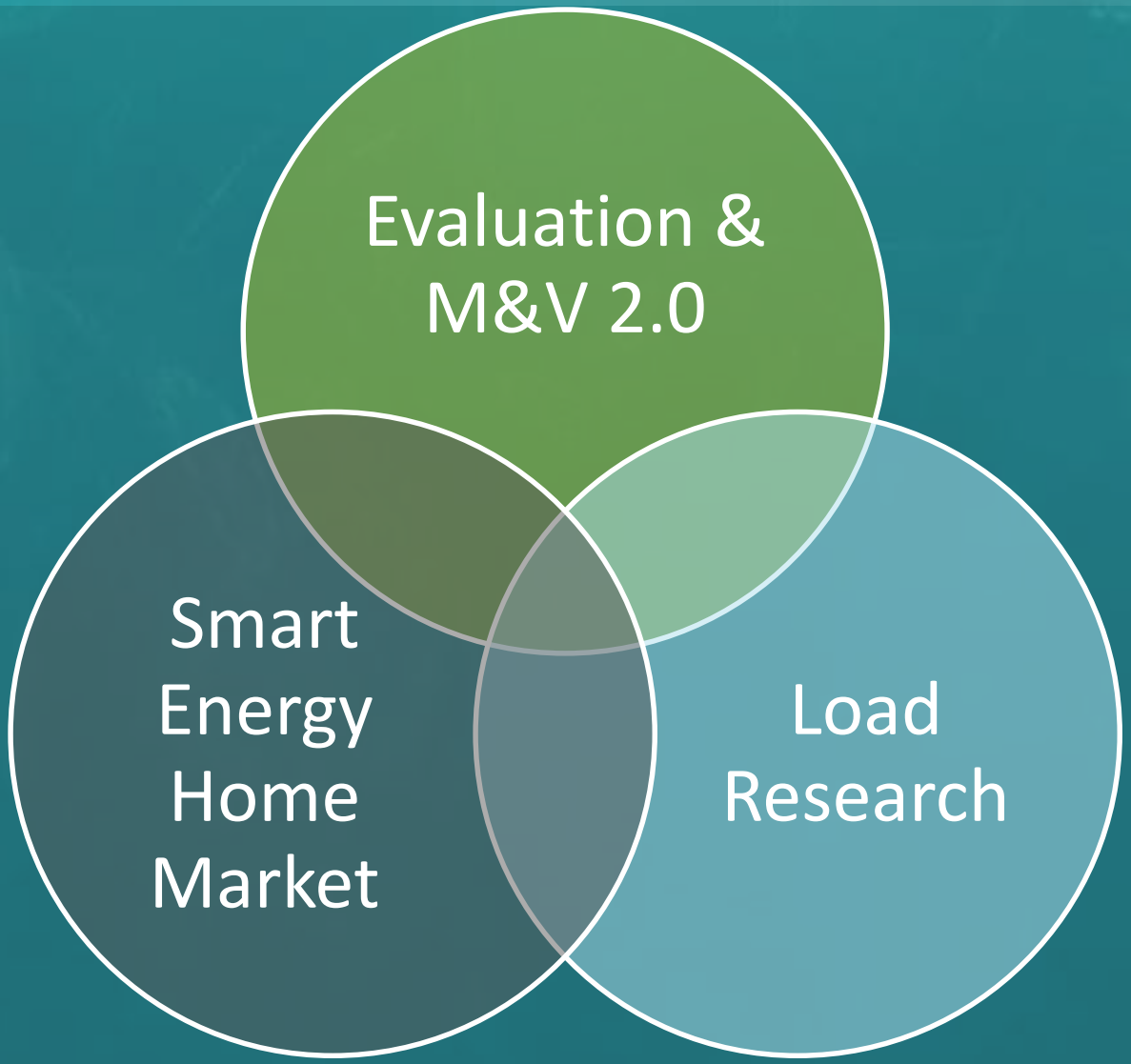
Advanced Efficiency Leadership Network

For 80% Carbon Reductions by 2050

NEEP Products & Services

- **Events & Stakeholder Engagement**
- **Research, Analysis, Reports, Case Studies**
- **Regional Market Transformation Strategies**
- **Technical Assistance & Web-based Resource Centers**

Why NILM?



Evolving Market

- NEEP has been tracking the smart home market for years
- Maintain an (unqualified) Products List online

As part of the HEMS Research Report, NEEP reviewed and updated inventories of HEMS technology from existing resources including a comprehensive list as part of the PG&E HEMS Market Charaterization, while expanding the inventory lists and providing costs and potential linkages where appropriate. The inventory chart below is the technology assessment from the NEEP HEMS Research Report with additions from web-scraping and a 2016-2017 PG&E HEMS Report. DISCLAIMER: NEEP does not take responsibility for the products listed here or for the accuracy of the information presented.

Download Spreadsheet

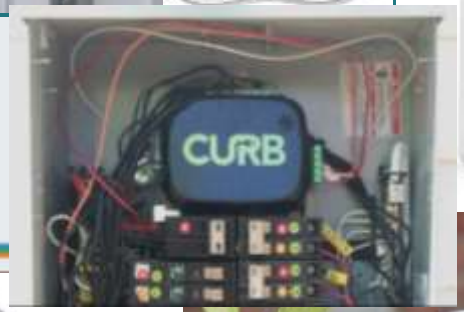
HEMS Technology Assessment

HEMS Technology Assessment: Last updated 2/2017			
Company	**Product**	**Description**	**Product Category**
1B First Build	Chill hub Smart refrigerator control	Chill Hub Smart refrigerator and smart refrigerator control hub	Smart Appliance
2Gig	GC-TBZ48 Z-Wave Programmable Thermostat		Smart Thermostat
3DFS	CurrentSEE	Real time energy monitoring with device level analytics for home and business	Load Monitor
Aclara	Behavioral Efficiency		Utility Facing Web Servi
Aclara	Customer Self Service		Utility Facing Web Servi
Aclara	Adaptive Consumer Engagement (ACLARA ACE™)		Utility Facing Web Servi

What is out there?

- 27 “Load Monitors” listed as smart home technologies (just on our list!)
- Costs from $15-250
- Range of functionalities offered, many consumer facing (i.e. expect consumers to purchase on their own)
  - Offer monitoring and control of a specific devices or outlet
  - Detecting and disaggregating electrical devices, making energy saving recommendations
  - Software, hardware, in the breaker panel, end use, or using AMI

Sampling of different products (Polls)



Let's get started!

- Presenters:
  - Dave Korn, Vice President of Energy Services, Cadmus
  - Terese Decker, Managing Consultant, Navigant

- Housekeeping:
  - Slides and recording will be uploaded in the next few days and shared with attendees
  - Please type in any questions as you have them during the webinar, but we will hold Q&A until the end




NILM: Examining Technologies and Selected Results

David Korn
Vice President – Engineering
The Cadmus Group

This slide contains Private and Proprietary Data of The Cadmus Group, Inc.

Disclaimer

- I will *neither* be praising nor burying NILM and disaggregation
  - I will not be naming any brand names or offering definitive conclusions about particular brands of NILM or LM
- We have some smaller pilot scale studies in progress
- Our larger scale parallel metering studies are ongoing

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What Do We Mean by NILM?

Literally:
Non-intrusive load monitoring

PNNL: an analytic approach used to disaggregate building loads based on a single metering point

Two parts:
1. a meter
2. software to separate loads

Why is the NILM Definition Important?

- It can inform or mislead the level of homeowner inconvenience
- It can limit the use of technologies in favor of others
- It is probably less important than cost and benefit

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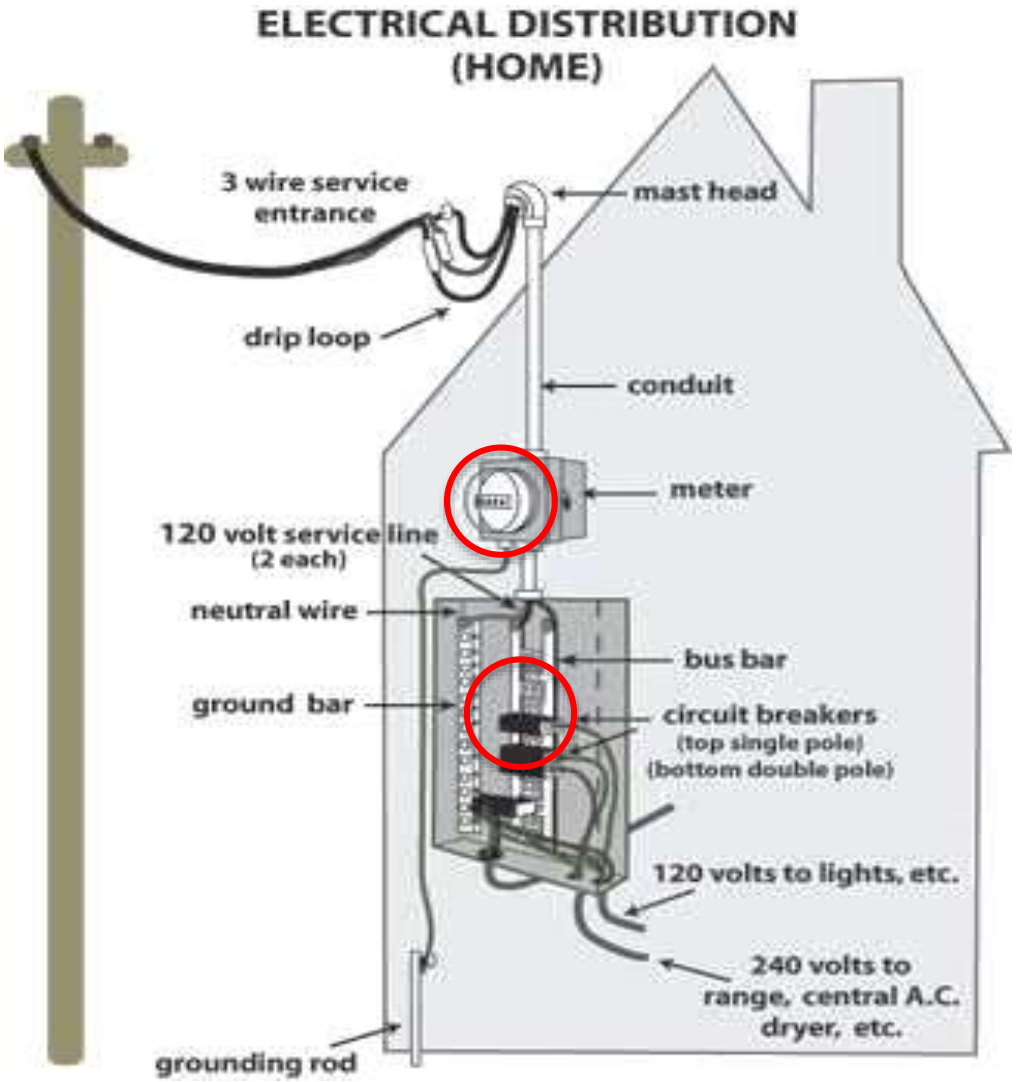
Two Meter Locations for Whole House Metering



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Load Metering

Whole House Metering

- Advanced meter infrastructure (AMI) meter/ wireless link
- Optical piggyback meter
- Utility meter collar piggyback meter
- In-panel current transformers (CTs)

(Direct) Load Metering

Panel

- In panel CTs and voltage taps
- In panel CT and external voltage taps
- Stick-on circuit meters that reside inside outer cover

At the load

- kWh transducers for HVAC
- Plug meters

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Meter Considerations

- Who owns the affected equipment?
- Are utility personnel required?
- Must the home be entered?
- Is an electrician required?
- Must the house be shut off?
- Must the load be shut off
- Is the customer's WiFi required?

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Levels of "Intrusion" of Load Metering

	Optical meter reader	Utility meter collar	AMI DAQ	Panel	At Load/ Plug
Equipment ownership	Utility	Utility	Utility	Home	Home
Utility personnel?	No*	Yes	Yes	No	No
Home entered?	No	No	No	Yes	Yes
Electrician?	No	Yes	No	Yes	No
Service shut off?	No	Yes	No	No*	No
Load shutoff?	No	Yes	No	No*	Yes-Plug, No-HVAC
Customer Broadband	Yes	Maybe	Maybe	Maybe	Maybe

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Tradeoffs of Approaches

	Optical meter reader	Utility meter collar	AMI DAQ	Panel Circuits	Panel Disag.	Plug
Logging **Frequency**	.1 - 1Hz	kHz	1 Hz	1 Hz	1 Hz - kHz	1 Hz
Accuracy	Low	Moderate	Moderate	High	Moderate	High
Cost	Low	Moderate	Low*	High	Moderate	High
"Intrusion"	Low	Moderate	Low	High	Moderate	High
Utility Broadband/ Storage Capacity	No	No	Yes	No	No	No

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Some Results

AMI/ machine learning

Disaggregation with high frequency whole panel metering

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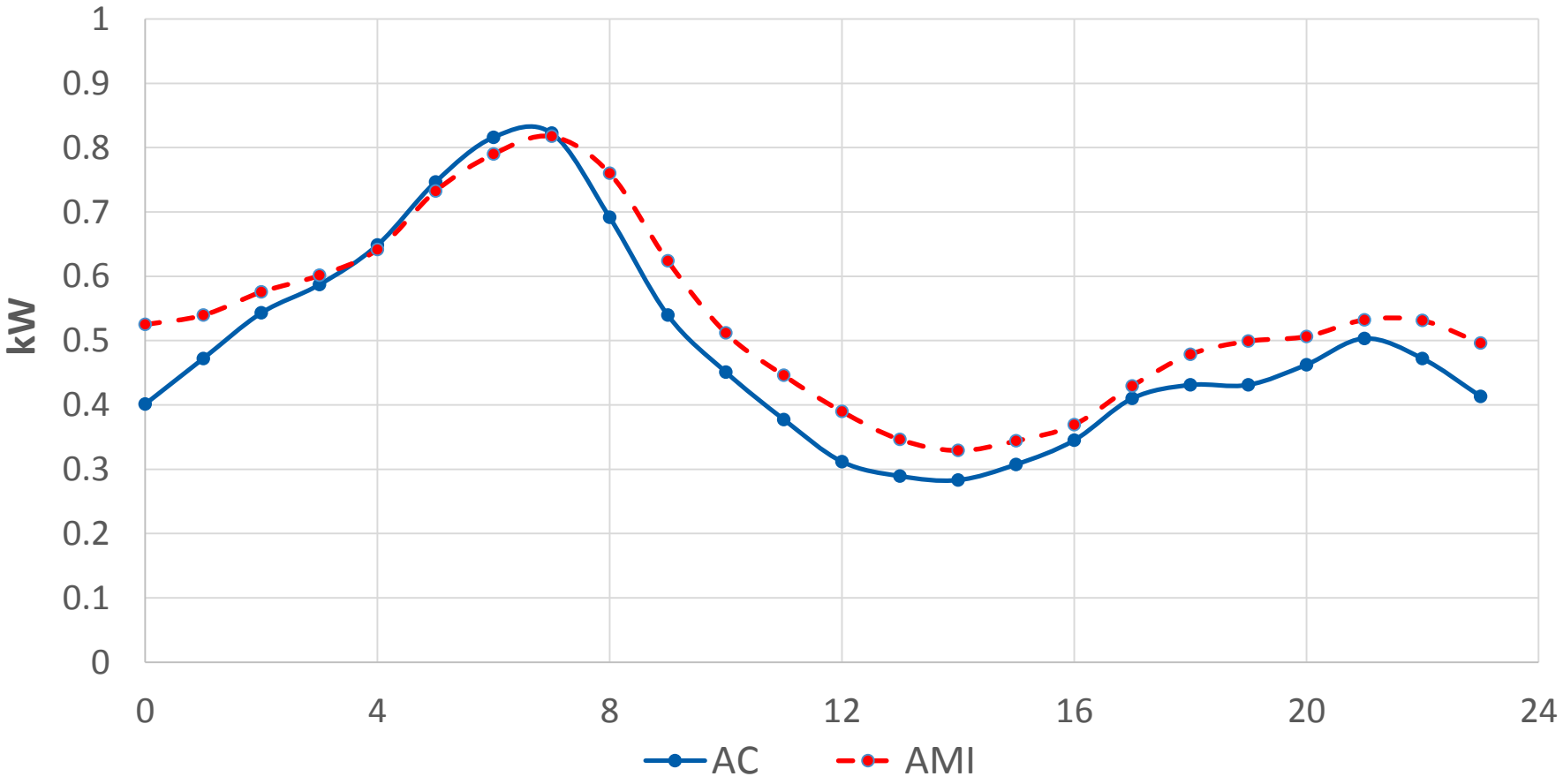
Machine Learning AMI vs Metered AC



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Well Pump-Results

	Load Metering	Disaggregation	
Number of cycles	129	128	99% level
False Positives	--	--	
False Negatives	--	1	<1%
Wattage	1,550W	1,560W/ 780W	Very accurate for no training, but sometimes misses a phase
kWh	2.66 kWh	2.43 kWh	About 10% low

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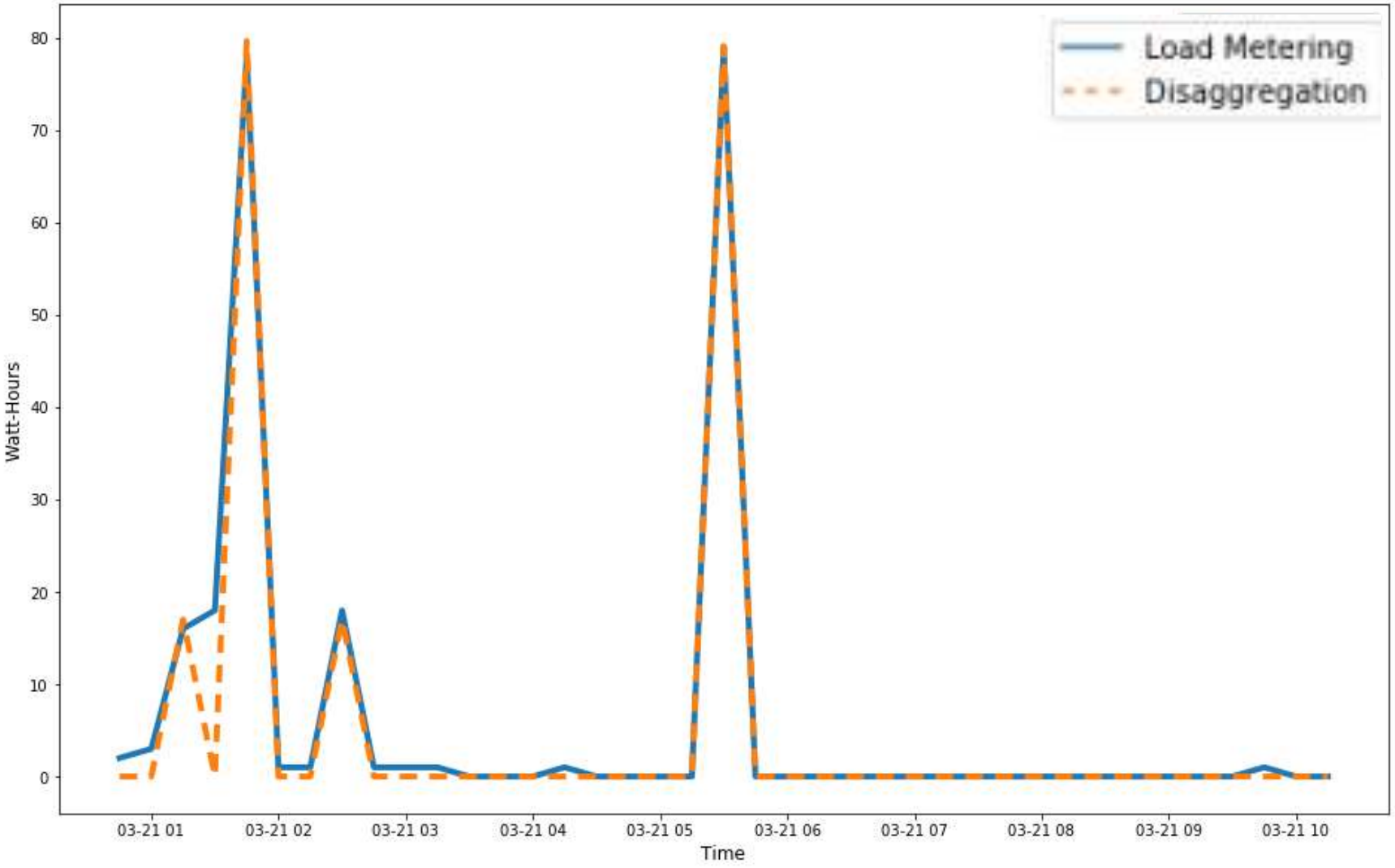
Example Disaggregation: Well Pump



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Wine Cooler-Results

	Load Metering	Disaggregation	
Number of cycles (all periods)	498	291	58% identified
Number of cycles (mid – 4am)	90	70	About 80% identified
False Positives	--	0	Rare
False Negatives	--	207	Appeared to miss more during the day
Average Wattage	76.3W	78W	Very accurate for no training
Energy use kWh	2.29 kWh	1.43 kWh	About 62%-artifact of missed cycles

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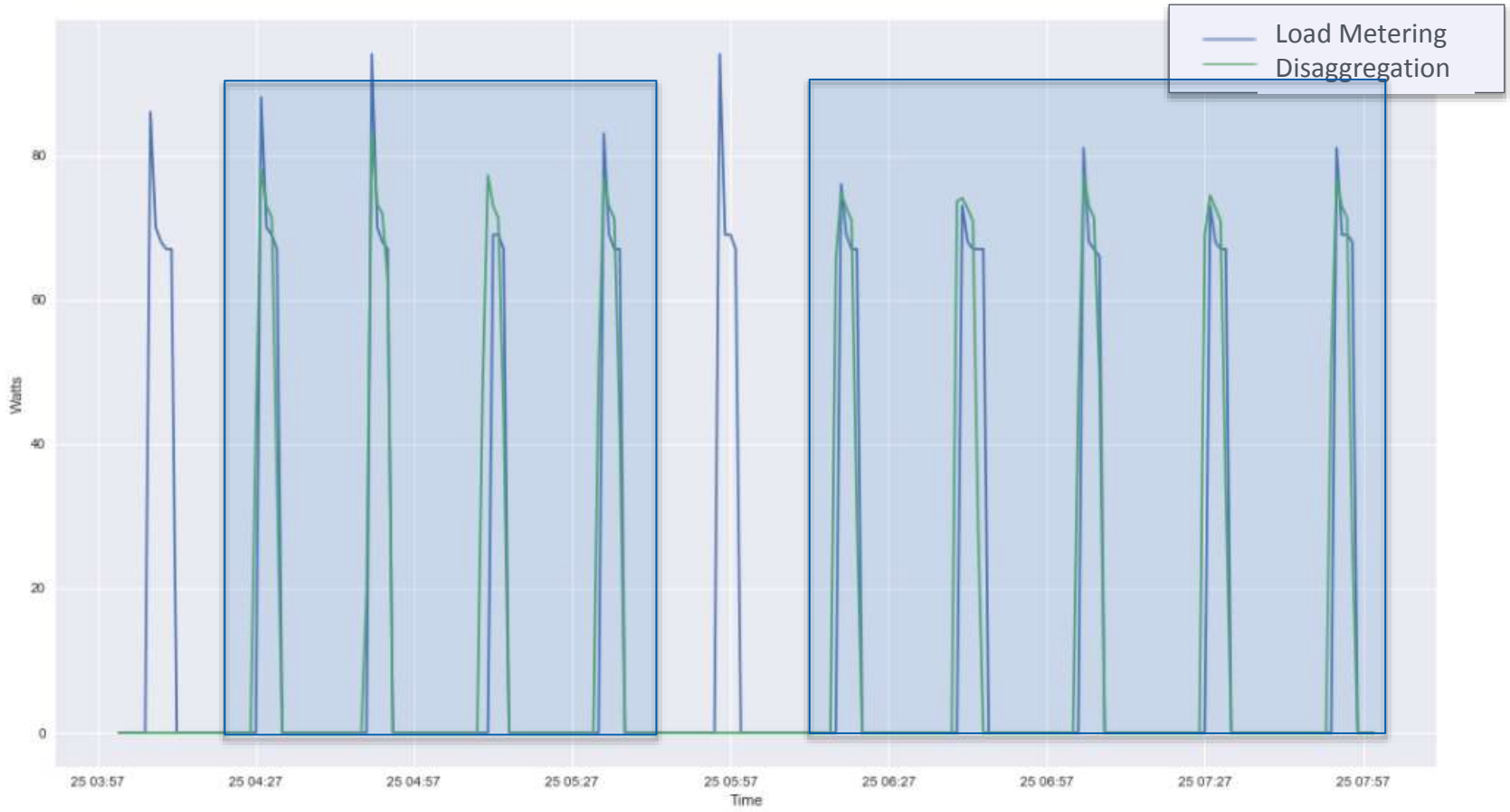
Small Wine Cooler

>80% Recognition at night



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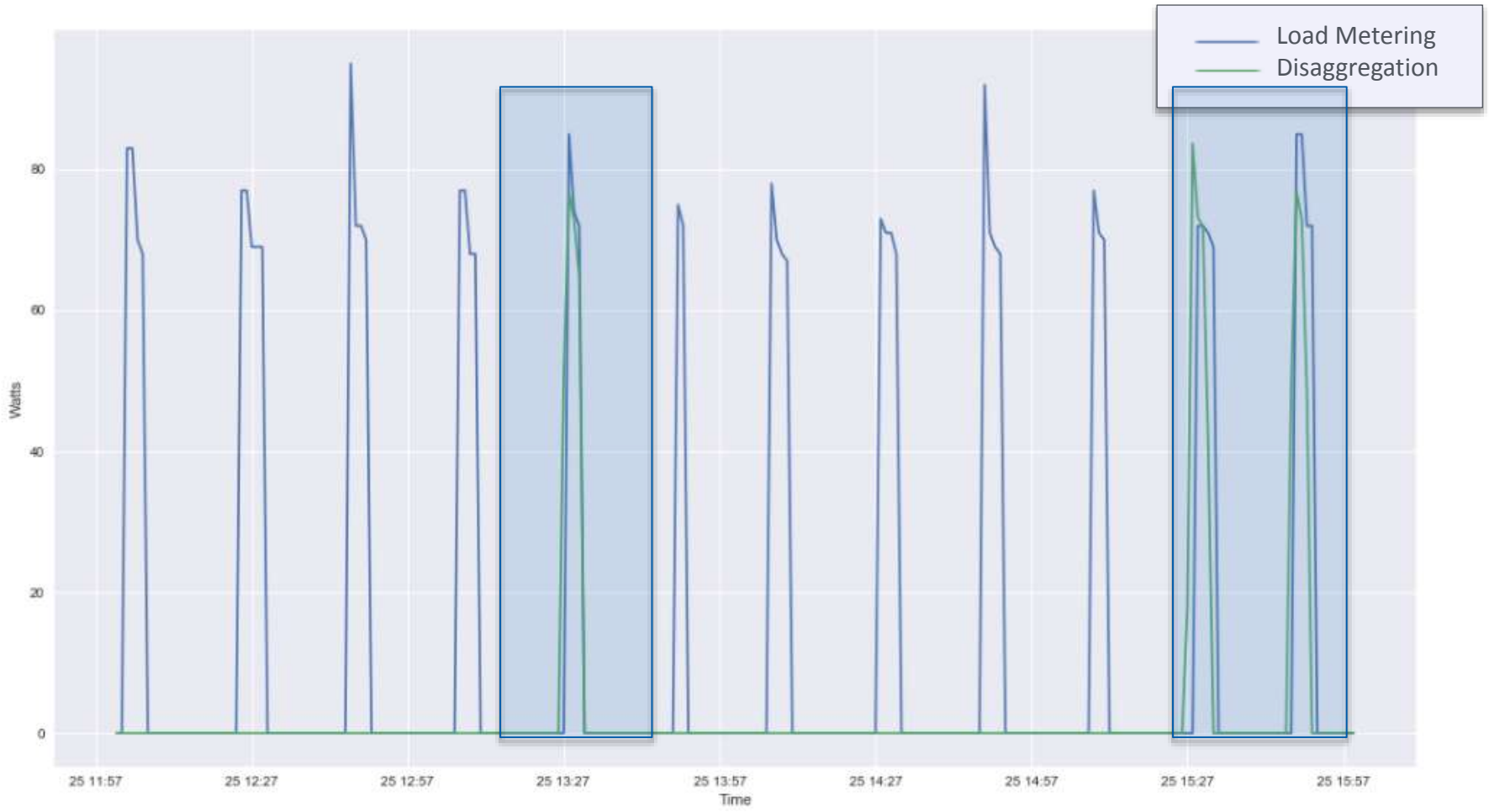
Small Wine Cooler

~25% Recognition during high loads



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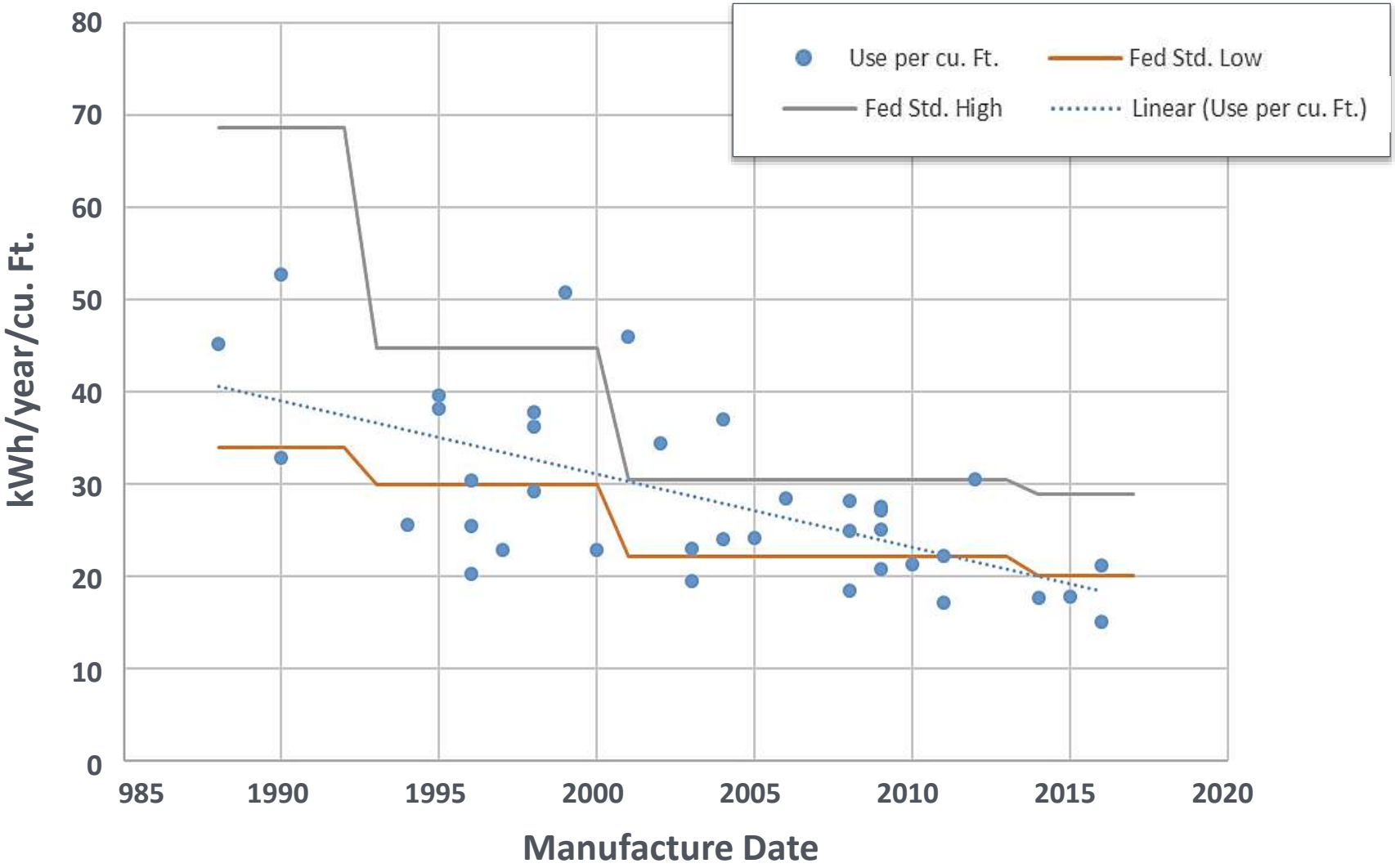
End Use Load Metering Example: Refrigerator



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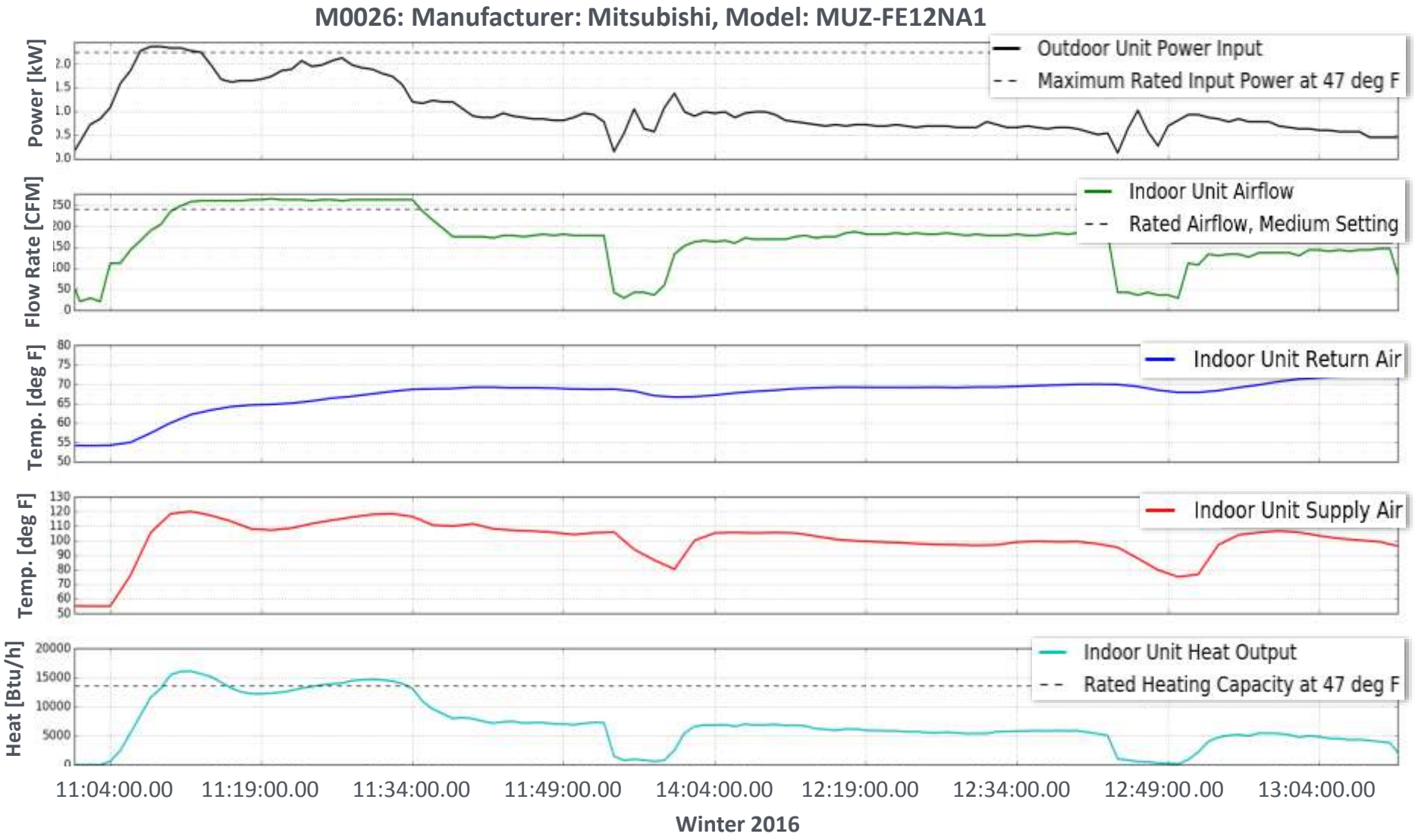
EULM Example: Ductless Heat Pump



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Possible Uses of NILM/ EULM

Consumer education

Behavioral savings

Load estimation

- Varies by timing and accuracy

Appliance fault detection

M&V

- DR
- Efficiency

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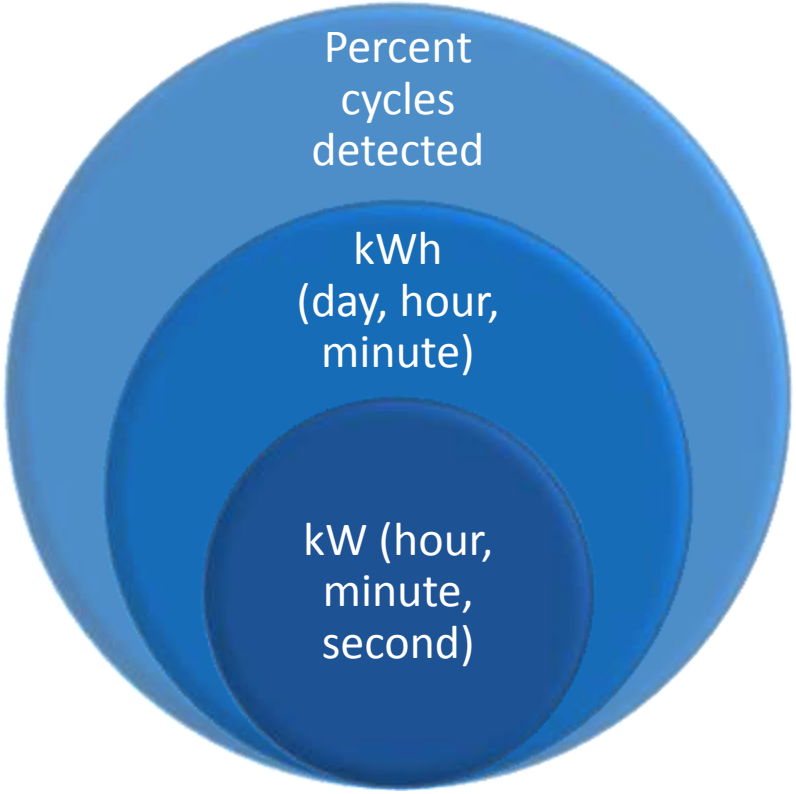
Measures of Accuracy

Proposed Accuracy Metrics



Typical NILM Result Format

Load	Daily kWh
Electric Vehicle Charger	88%
Solar	83%
Pool Pump	81%
Refrigeration	78%
Water Heater	67%
HVAC	63%

Source: Report to SDGE

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What Does the M&V Industry Need?

An agreed way for measuring disaggregation success

For general consumption:

- Daily totals of major loads at better than 90% accuracy

For M&V of kWh (depends on savings level):

- Daily totals of major loads at better than 93% accuracy for large savings, and 97% for smaller savings

For time of day load shapes:

- Hourly totals of major loads at better than 90% accuracy
- Correct identification of >90% of use cycles

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COMPARING END USE METERING AND NILM

A DECISION MAKING CASE STUDY

PREPARED FOR NORTHEAST ENERGY EFFICIENCY PARTNERSHIPS (NEEP) WEBINAR

31 JULY 2017

NAVIGANT

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NILM Approach

Key Takeaways

Discussion

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STUDY GOALS

Client

Massachusetts Program Administrators and Energy Efficiency Advisory Council

Study goal

Fundamentally understand current and future statewide energy usage and peak demand by end use for program planning, potential studies, market effects research, etc.

Specific research questions

- What kind and efficiency equipment is present in MA homes?
- How and when are people using their equipment?
- Why do people use their equipment the way that they do?

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STUDY GOALS

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Specific research questions

- What kind and efficiency equipment is present in MA homes?
- How and when are people using their equipment?
- Why do people use their equipment the way that they do?

Focus of today's discussion

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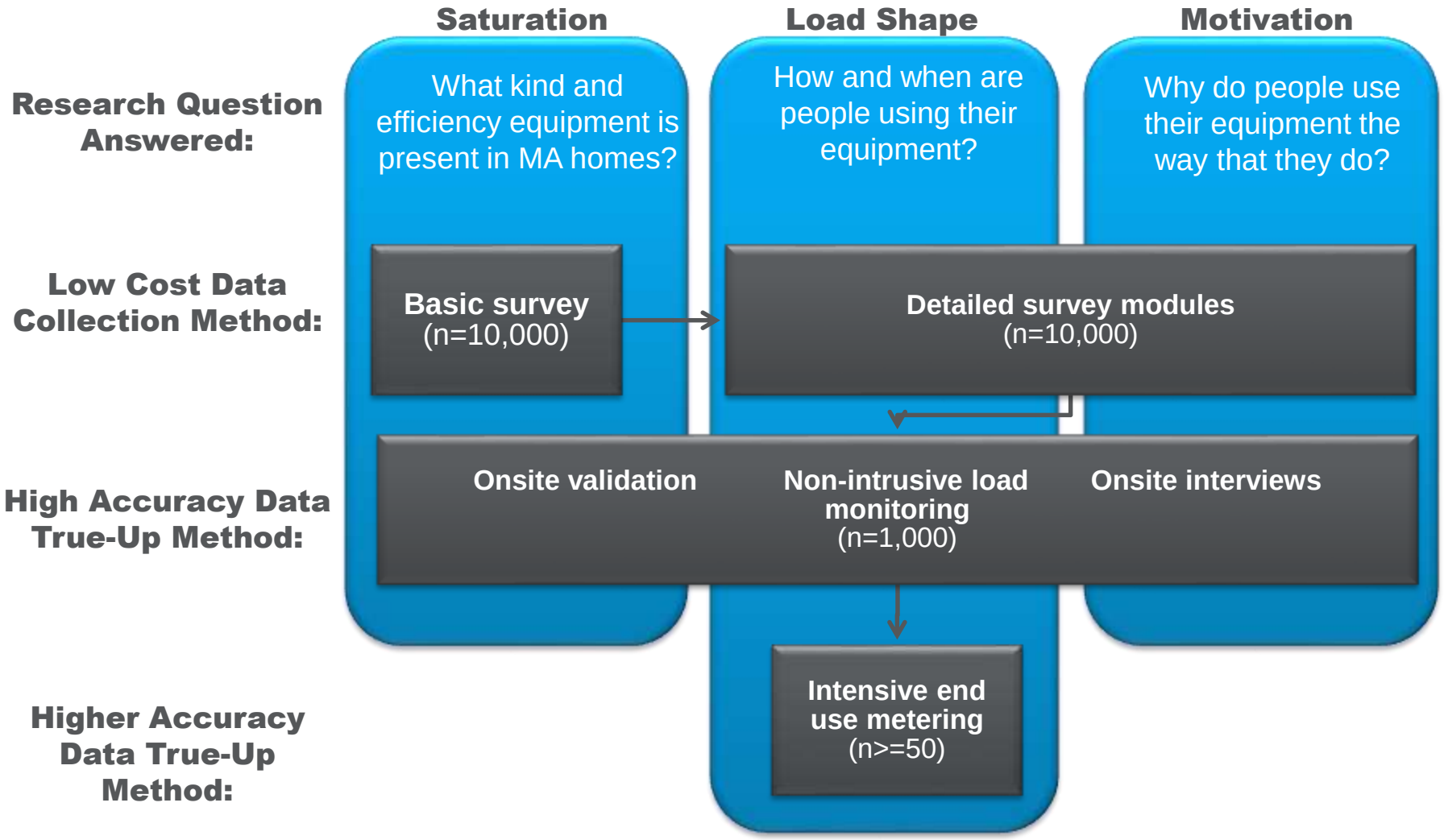
APPROACH OVERVIEW



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HOWEVER….

This research approach seemed risky to all parties.

- Accuracy of NILM is uncertain, not all results have been tested/published
- Installation of utility-side meters required regulatory approval in other states
- There's not much AMI data in relevant jurisdiction, so NILM requires data collection
- Logging in panel requires electrician, which is very intrusive
- Possible to use multiple software solutions with one or more hardware solution(s), but hard to know which to use without testing
- It's difficult to scope all of this work without trying some things out.
- There was a lot of budget risk on both sides and we wanted to be sure the study was designed correctly so that we didn't waste money.

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SO….

We decided to test multiple approaches first.

- Ran an end-to-end test (“Phase 1”) on ~10% of the proposed sample using multiple approaches to determine best measurement and analysis methodologies, then plan full scale study (“Phase 2”) using results of test.
- Final sample sizes:
  - Online survey: 600
  - Whole-premise metered and disaggregated: 45
  - End-use metered: 23

See Riley Hastings’ and Justin Spencer’s presentation at IEPEC next week about phasing the research:
Wednesday, August 9th 8:30am-10am. Abstract here.

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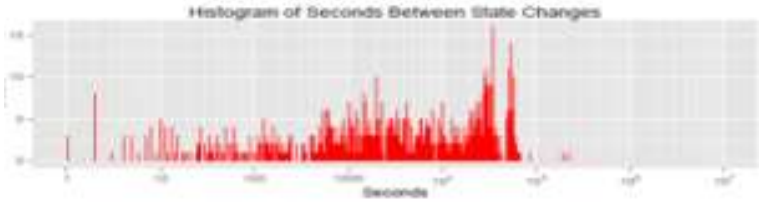
WE CONSIDERED SEVERAL NILM SCHEMES

Optical Sensor

Server-based Disaggregation

Smart Meter

Gateway



CT Sensors

Utility Meter

Local Disaggregation

Navigant Analysis

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WE USED ONE APPROACH WITH SEVERAL METHODS

Optical Sensor

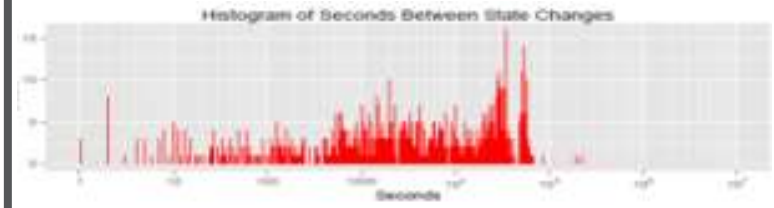
Server-based Disaggregation

Used optical whole premise energy meter because it is the simplest and easiest to install (most non-intrusive).

Compared three server-based disaggregation methods:

- Open-source machine learning (Navigant)
- Econometric (Navigant)
- Proprietary (third party)

Used CT-based meters to measure individual end uses and whole premise energy consumption for comparison testing and true up.



Navigant Analysis

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DISAGGREGATION METHODS EMPLOYED

The team tested and compared the following three NILM approaches:

- **Open-source (Navigant)**: machine learning approach used to "detect" appliance loads at individual house level at medium temporal resolution (1 minute)
- **Econometric (Navigant)**: using data across households to determine individual appliance load profiles (hourly)
- **Proprietary (third-party provider)**: proprietary algorithms based upon machine learning approach

See Justin Elszasz's presentation at IEPEC next week about the details of the three NILM approaches and outcomes:
Thursday, August 10th 8:30am-10am. Abstract here.

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NILM TESTING FRAMEWORK

Coefficient of variation (CV) is key performance metric for evaluation.

- Measures variability of appliance draw predictions with respect to the mean of the measured appliance draws
- Model with lower CV than measured CV for an appliance indicates more precise predictions

Key factors for measuring success of NILM approaches include:

- Energy consumption for the logged period, in aggregate across sites
- Energy consumption during the ISO and utility peaks
- Hourly energy consumption, aggregated across sites

Sliced the data by:

- Five time-of-day bins
- Day type (weekday vs. weekend/holiday)
- Season (cooling season vs. shoulder season)

$$CV = \frac{Standard\ Deviation}{Mean}$$

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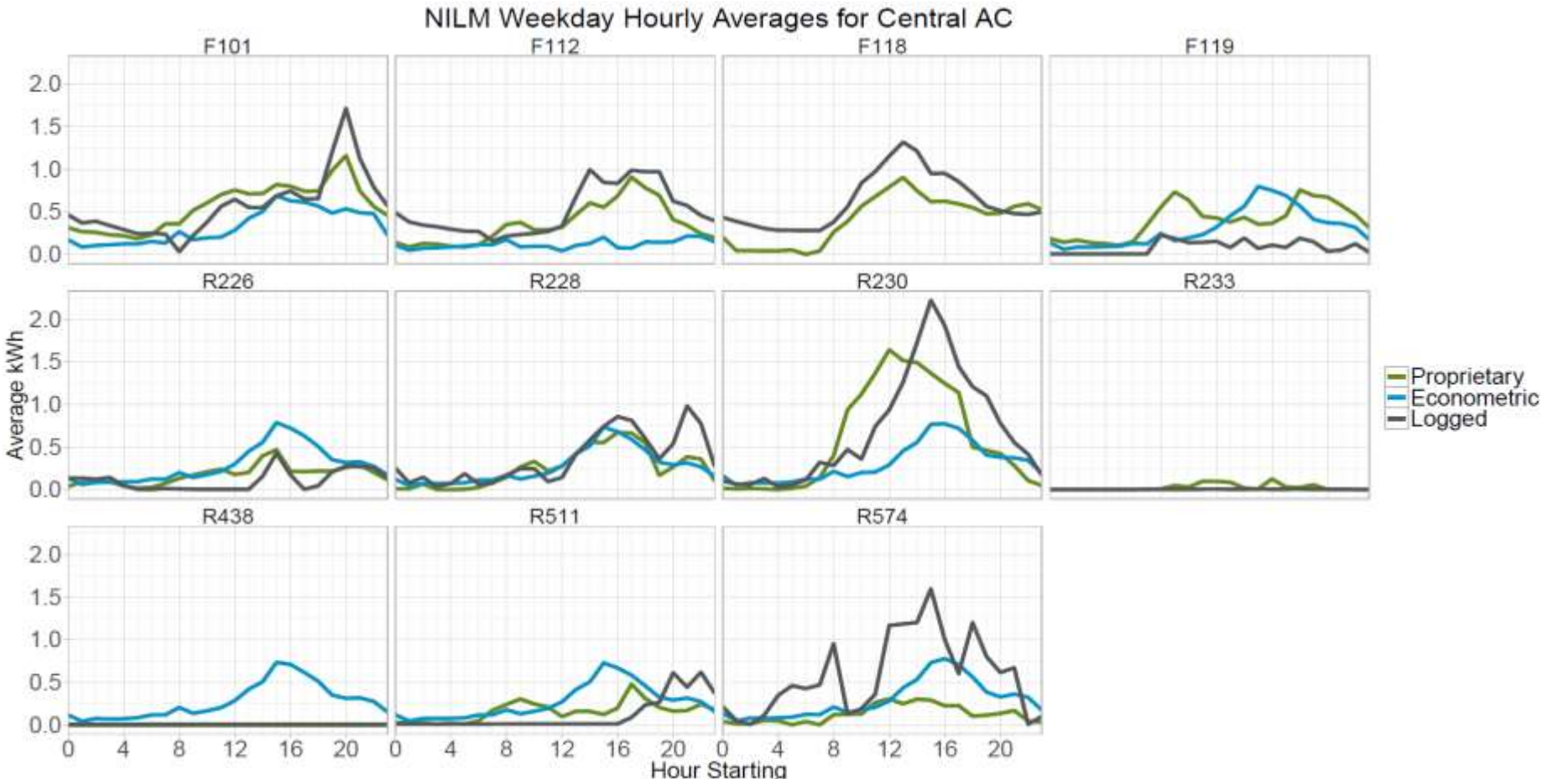
SUBJECTIVE COMPARISON OF SITE LEVEL RESULTS



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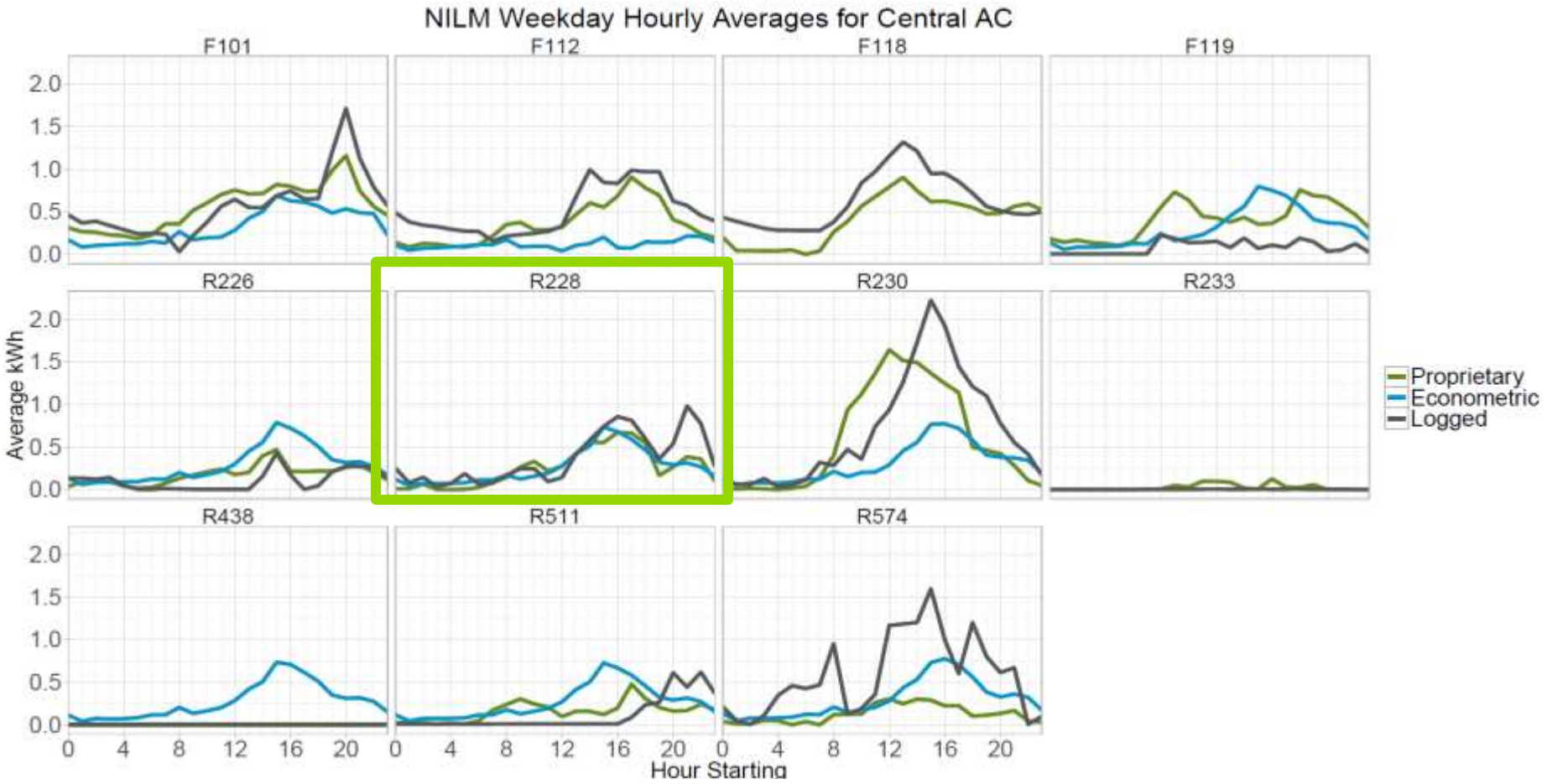

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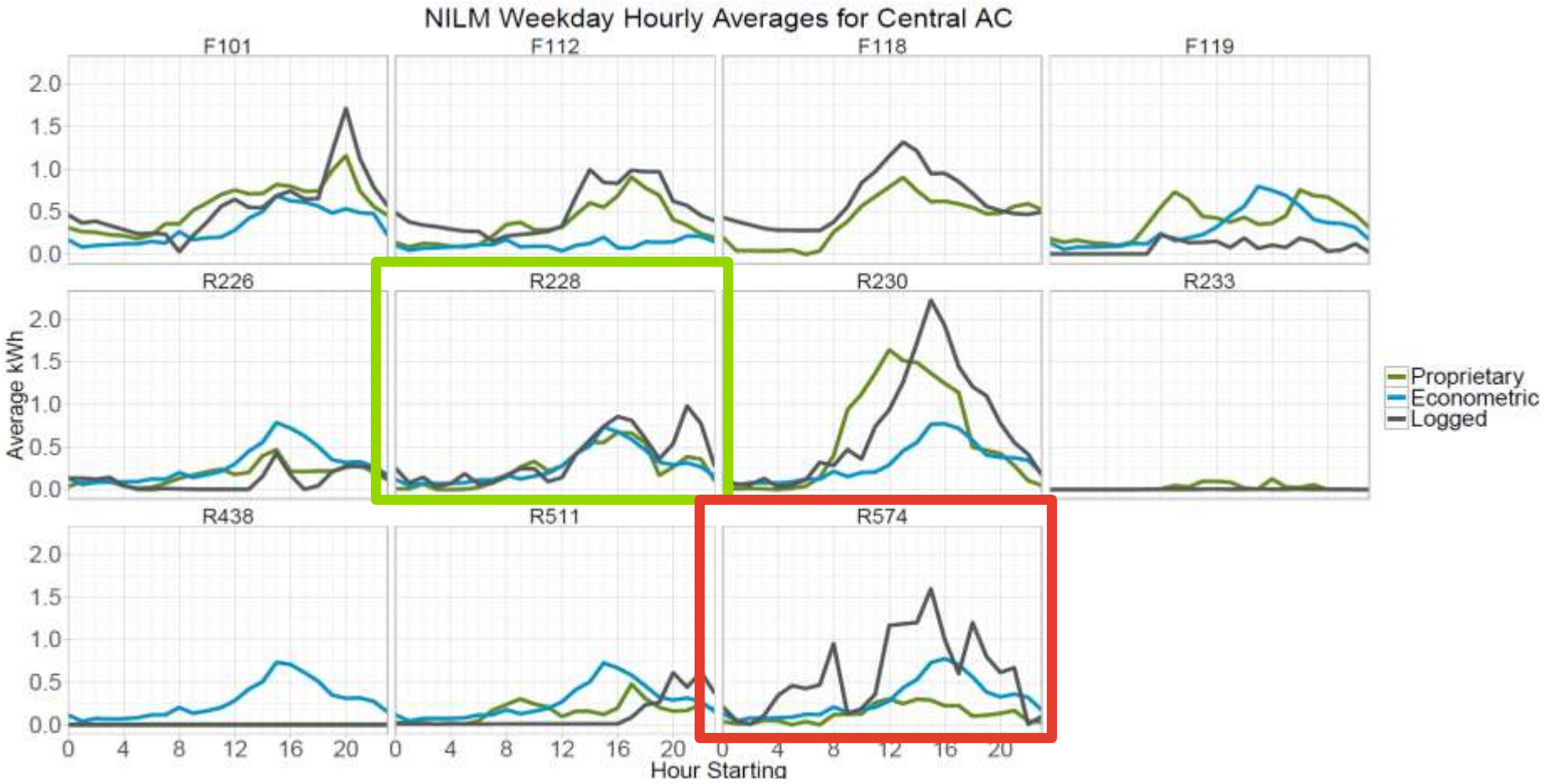
SUBJECTIVE COMPARISON OF SITE LEVEL RESULTS



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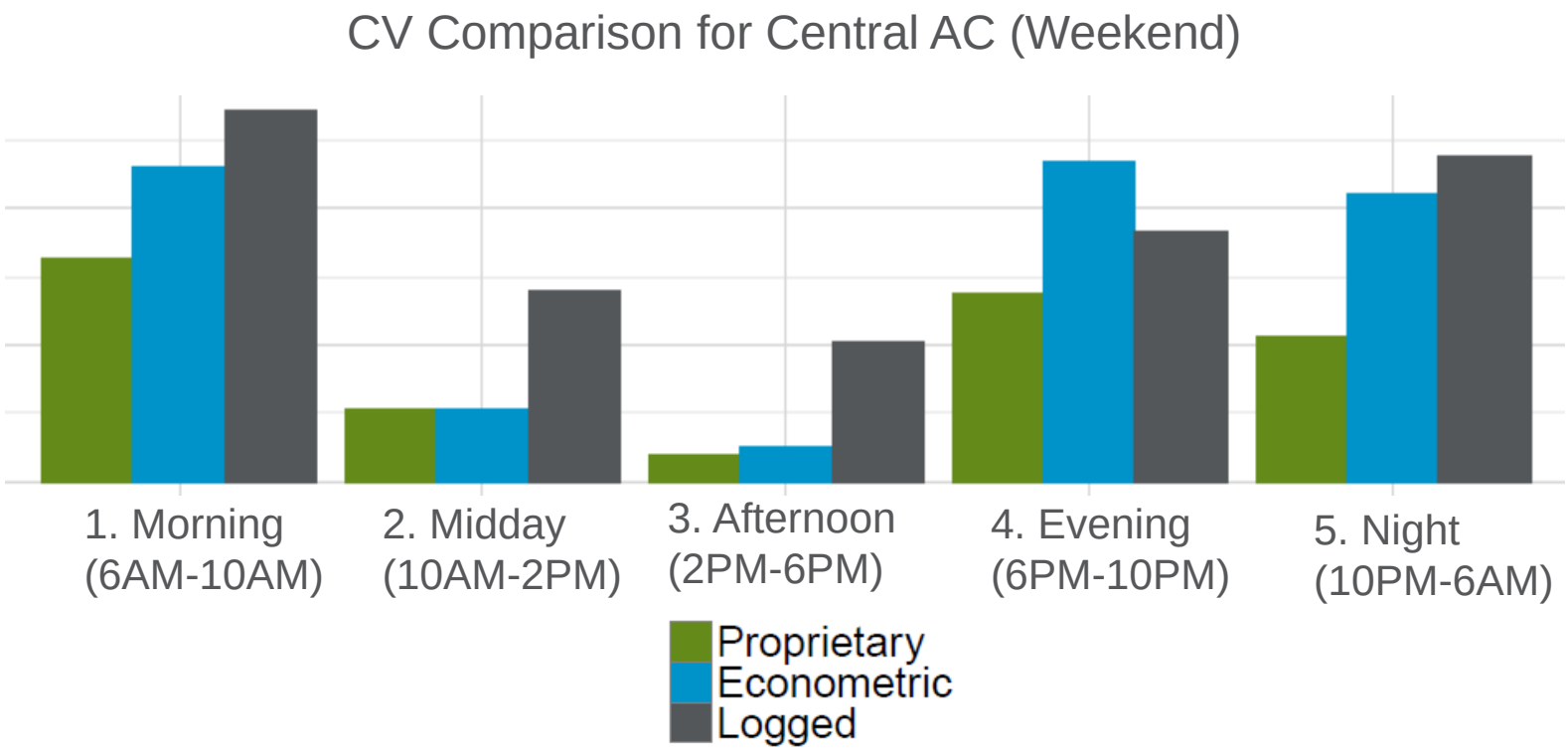
OBJECTIVE COMPARISON OF SITE LEVEL RESULTS



For NILM to provide leverage to metered data, we are looking for the green and blue bars to be shorter than the gray bar in all time-of-day bins.

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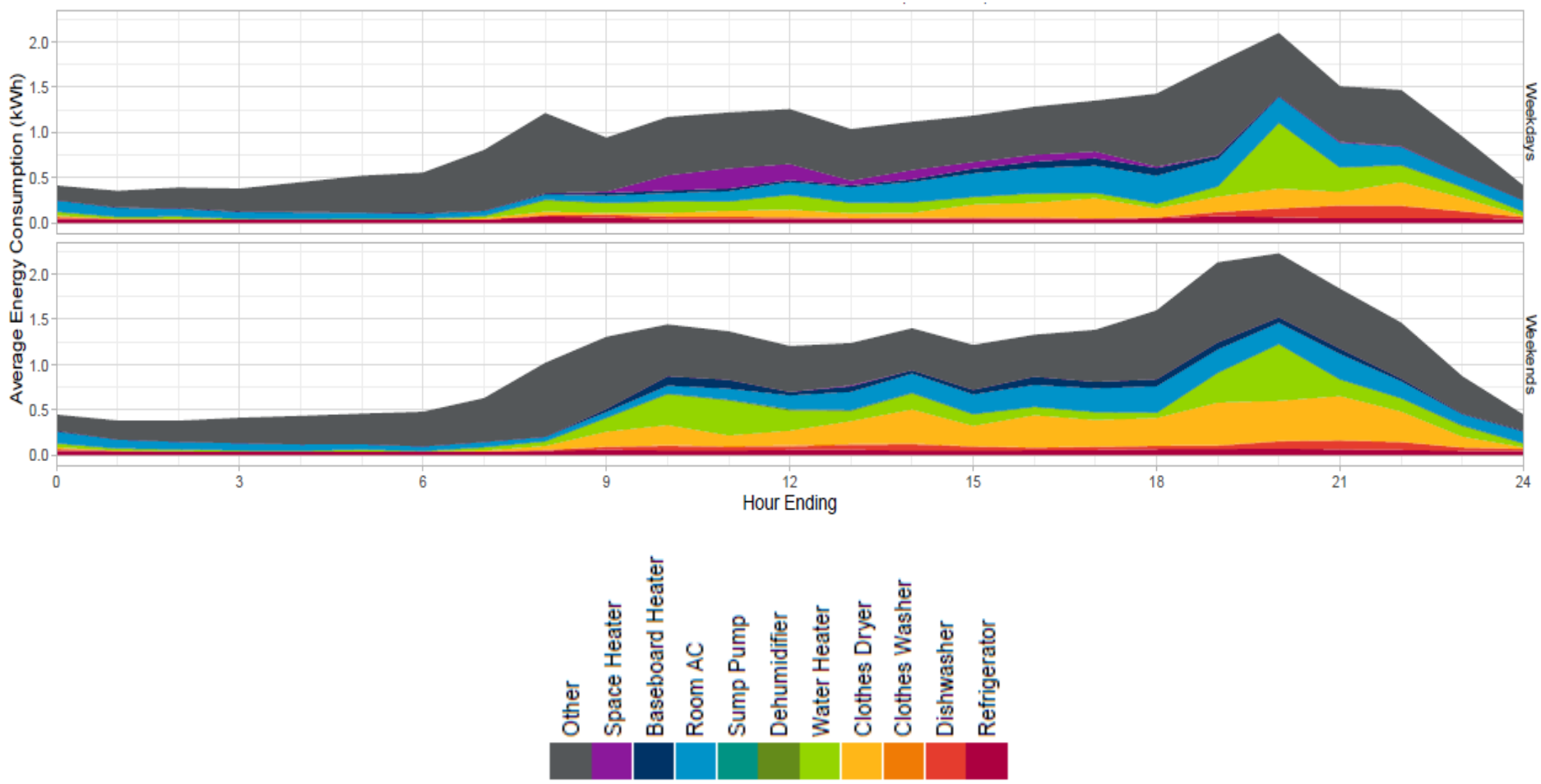
1. END USE METERING WORKED BETTER THAN EXPECTED



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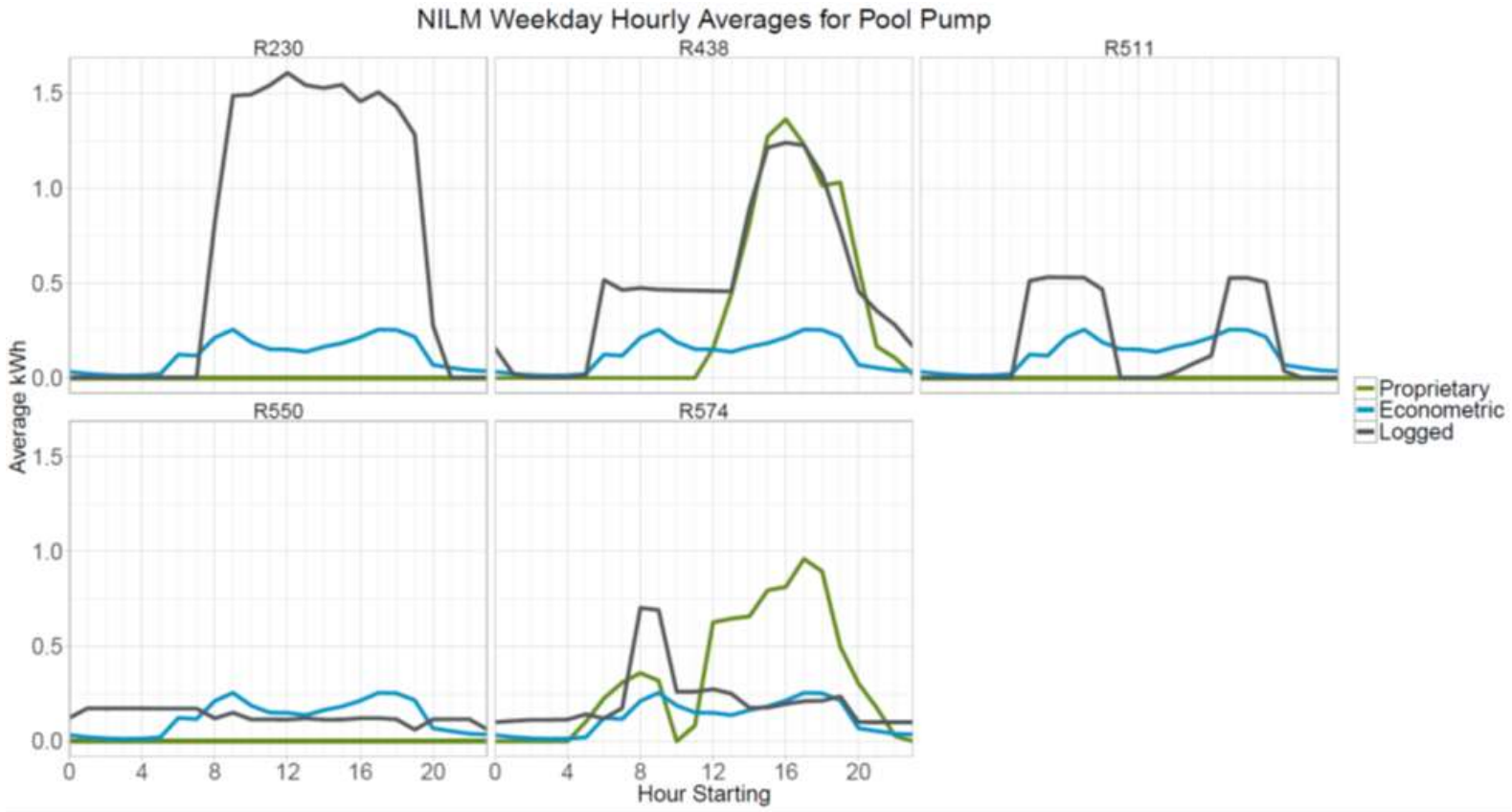
2. WE HAVE THE DATA TO UNDERSTAND LOAD VARIABILITY

Most of the end uses have lots of variability between sites – both in the shape and the overall usage, which increases the NILM CV.



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3. MEASURED DATA QUALITY MATTERS TO SAVE TIME

The CT-based meter collects better data than the whole home optical meter. The time required to install the CT-based meter is balanced by the time to maintain the whole home optical meter.

Metric	Whole Home Optical Meter	CT-Based Meter
Equipment Cost	$144 / site	$520 / site
Installation qualifications	None	Electrician
Time to install	0.5 hours / site	3 hours / site
Time to maintain	2.5 hours / site	0.5 hours / site
Raw data quality	Fair	Excellent
Communication	WiFi Bridge	Powerline Carrier

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4. DISAGGREGATION WORKS FOR SOME END USES

End Use Category	End Use	Proprietary Disaggregation Status	Econometric Disaggregation Status
Heating and Cooling	Central AC	PASS	PASS
	Room AC	PASS	FAIL
	Electric Resistance Heat	Insufficient data – season	Insufficient data – season
	Space Heaters	Insufficient data – season	Insufficient data – season
	Boiler Circulator Pump	Not tested	Not tested
	Furnace Fan	Not tested	Not tested
	Central HP	Insufficient data – season	Insufficient data – season
	Ductless HP	Insufficient data – season	Insufficient data – season
DHW	Hot Water Heater	Insufficient data – too few sites	Insufficient data – too few sites
Kitchen	Dishwasher	FAIL	Not tested
	Second Refrigerator	Insufficient data – too few sites	Insufficient data – too few sites
	Freezer	Not tested	Not tested
	Refrigerator	FAIL	Not tested
Laundry	Clothes Washer	Not tested	Not tested
	Clothes Dryer	FAIL	FAIL
Miscellaneous	Dehumidifier	Not tested	FAIL
	Aquarium	Not tested	Not tested
	Well Pump	Not tested	Not tested
	Sump Pump	Not tested	FAIL
	Pool Pump	FAIL	FAIL

5. SOME END USES ARE HARDER TO METER THAN OTHERS

We would gain the most leverage from not needing to meter 120V hardwired loads, but NILM is currently underdeveloped for these end uses.

240V Hardwired Loads

- Easy to meter with CT-based meter (no circuit tracing necessary)
- Examples:
  - Central cooling/heat
  - Domestic hot water
  - Some pumps

120V Plug Loads

- Easy to meter with plug load meters
- Examples:
  - Room AC
  - Space heater
  - Dehumidifier
  - Clothes washer
  - Aquarium
  - Fridges/freezers
  - Dishwashers

120V Hardwired Loads

- Hardest to meter (requires CT-based meter + circuit tracing)
- Examples:
  - Boiler circulator pump
  - Furnace fan
  - Some pumps

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KEY TAKEAWAYS

01 End use metering worked better than expected

02 We have the data to understand load variability

03 Data quality matters primarily because it saves time

04 Load disaggregation works for some end uses

05 Some end uses are harder to meter than others

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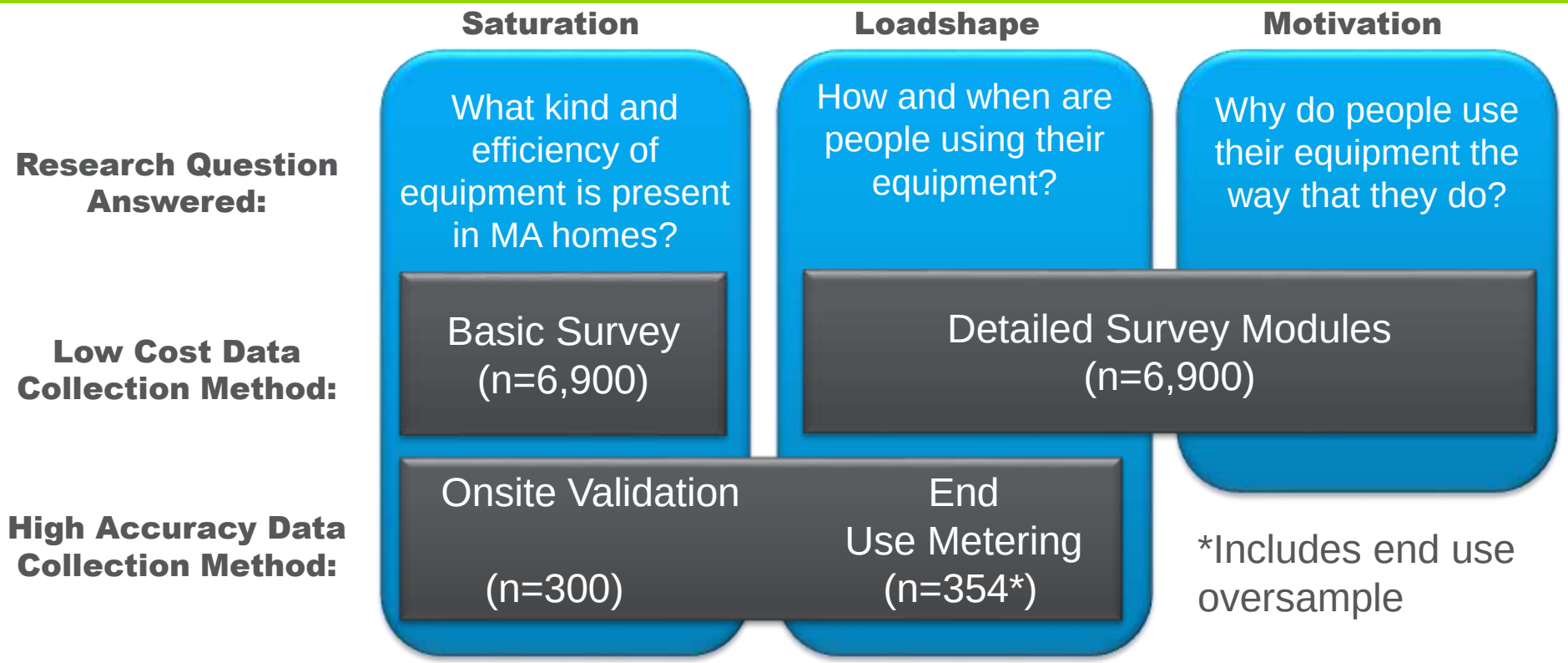
FINAL STUDY DESIGN



See my presentation at IEPEC next week about three load shape development case studies:
Thursday, August 10th 8:30am-10am. Abstract here.

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Discussion, Q&A

- Last Poll
- Please type in your questions. We will get through as many as possible during the webinar, but will work to answer all questions after the fact

Mark Your Calendar

- IEPEC Evaluation Conference
  - Baltimore, MD: August 8-11, www.iepec.org
- AESP Technology Conference
  - Toronto, Canada: August 30-31, www.aesp.org
- NEEP's EM&V Forum Fall Meeting
  - Hartford, CT: October 3, www.neep.org/events
- NEEP's New Hampshire Schools Summit
  - Meredith NH, October 20, www.neep.org/events
- Industrial Strategic Energy Management Workshop in November and other events:
  - Check out our Industry Calendar:
  - http://neep.org/calendar

THANK YOU

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