Residential Electricity End-use Disaggregation Using Whole Home Disaggregation Technologies

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Josh Butzbaugh and Ebony Mayhorn, Pacific Northwest National Laboratory, and Bill McNary, U.S. Energy Information Administration

Agenda

- Background
- Submetering and Load Disaggregation Technology
- Phase I
- Data and Results
- Lessons Learned
- Next Steps – Phase II
- Conclusion

Background

Residential Energy Consumption Survey (RECS)

40 year program of benchmark energy usage information collected via the Residential Energy Consumption Survey (RECS) and the Commercial Buildings Energy Consumption Survey (CBECS)

- Phase 1: Nationwide sample surveys using in-person interviews to collect building/household characteristics (voluntary)

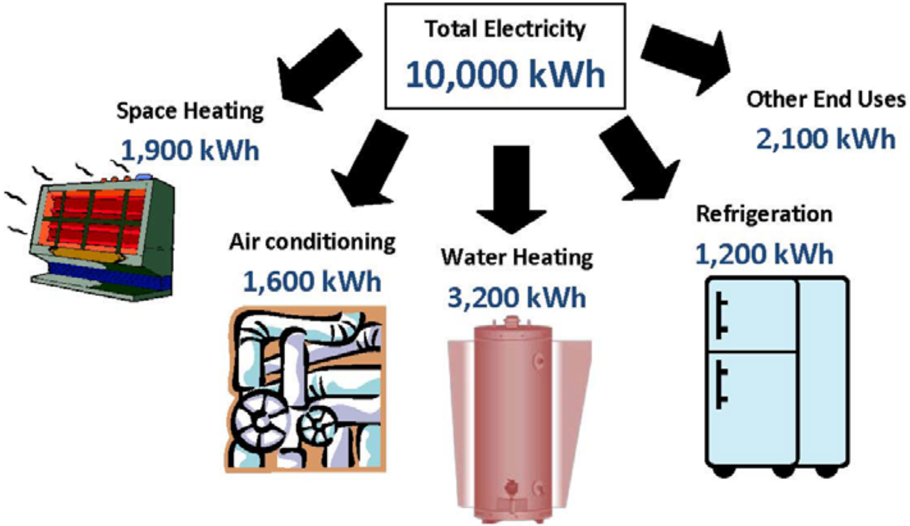
- Phase 2: Follow-on collection of utility billing data from suppliers (mandatory)

- Phase 3: Modeled end-uses

Background

RECS End-Use Modeling

Given the *annual* total residential energy consumption for a specific fuel, how does it decompose into end uses such as space heating, air conditioning, water heating, etc?



Background

Goals of EIA residential submetering and load disaggregation project

- Simultaneous collection of characteristics and consumption data using whole home submetering technology
- Validation of current RECS end-use models
  - Confirm coverage of end-uses
  - Confirm accuracy of modeled end-uses
- Additional collection of new, smaller end-uses (miscellaneous end uses)
- Real time updating of new energy-using products in the home
- Prioritize the research:
  - Tier 1 – Refrigerators, Dishwashers, Clothes Washers, Dryers, Cooking, Air Conditioning, Heating, Water Heating
  - Tier 2 – Computers, Televisions, Home Entertainment
  - Tier 3 – Lighting, Rare End Uses, Residual

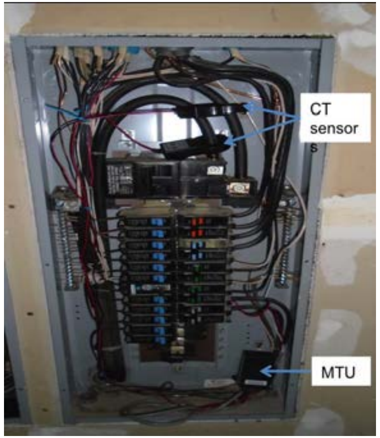
Background

PNNL Plan

- Evaluate applicability of disaggregation to improve RECS
  - Evaluate disaggregation performance and accuracy
  - Develop protocols for installing and maintaining equipment as well as gaining consumer acceptance
- Phase I: Validate performance
  - Eight homes in Portland, OR for two years
  - Source of truth submeter for major circuits + testing of disaggregation technologies
- Phase II: Augment existing pilot
  - Complementary task with AMI data disaggregation
  - Through late 2019

Submetering & Disaggregation Technology

Disaggregation with different sources of inputs



CT sensors installed in breaker panel

Utility meter adapter/recorder

Utility meter wireless sensor

EMF sensor installed at breaker panel

Data from the Utility Smart meter

Submetering & Disaggregation Technology

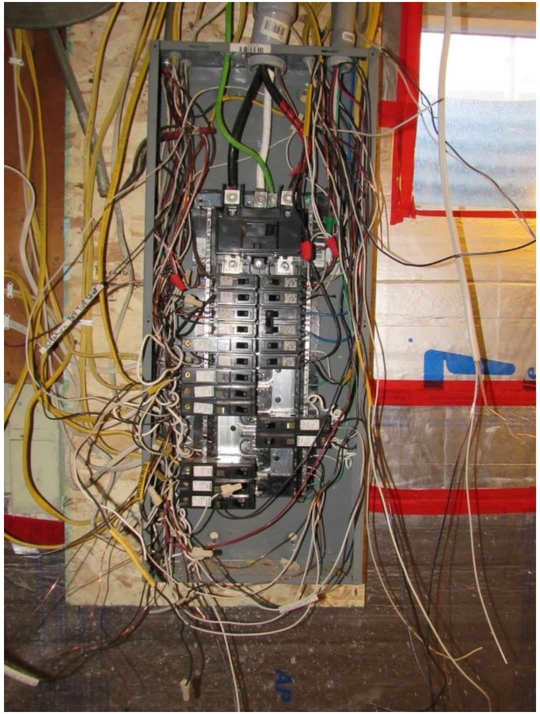
	Ground Truth	Product A	Product B	Product C
Technology	Submeter	Disaggregation	Disaggregation	Disaggregation
Hardware Cost ($)	$720	$270 (+$50 for PV)	$160	$780
Labor to Install & Setup	8 hours	1 hour	15-45 min	5 hours
Labor to Remove	4 hours	1 hour	None	2 hours
Estimated Total Cost ($)	$2,200	$600	$300	$1,600
Electrician to Install?	Yes	Yes	No	Yes
WiFi Performance	Average	Good	Poor	Good
Maintenance Support	Low	Low	High	Low

Product B changed algorithms

Product C removed from evaluation

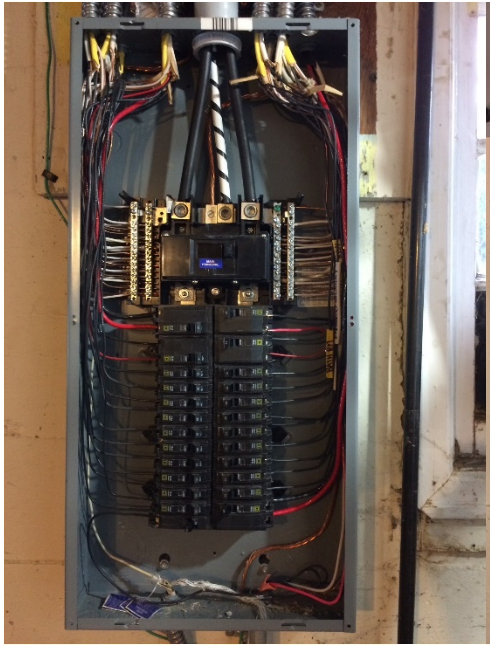
Phase I

- Recruitment – PNNL staff candidates (Portland, OR)
  - Number & locations of electrical panels (with pictures)
  - Electric loads
  - Unique loads
- Homeowner agreements
  - PNNL legal and contracts offices
  - Data privacy
- Subcontractor selection
  - Local presence
  - Communications & electrical engineering expertise

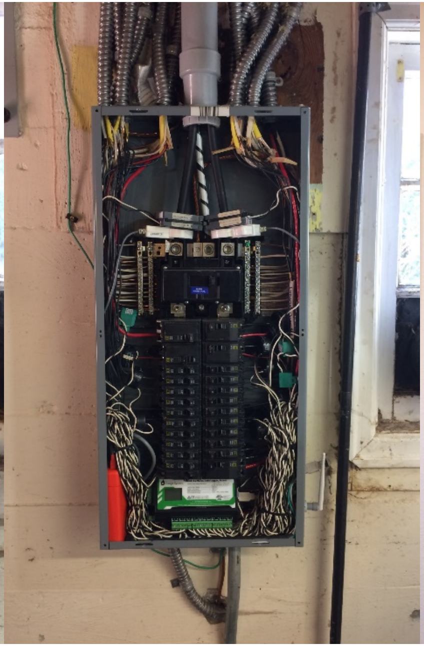


Avoid!

Phase I



Before



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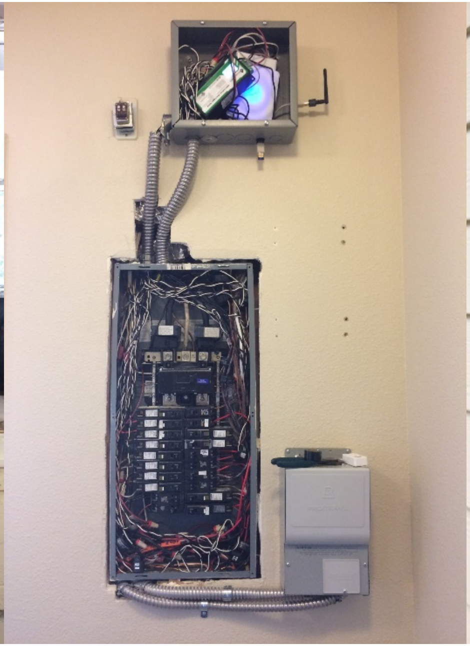


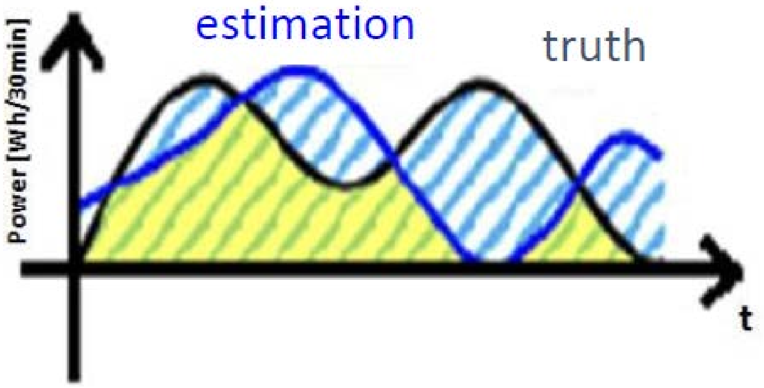
External Enclosure

Attached to Utility Meter

Data and Results

Match Rate (MR) demonstrated as a good measure of accuracy

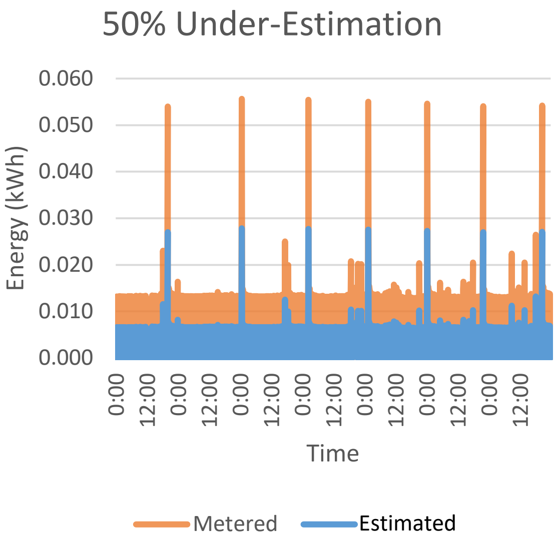
$$\text{MR} = \frac{\sum_{i=1}^{N} \min\{E_i, \hat{E}_i\}}{\sum_{i=1}^{N} \max\{E_i, \hat{E}_i\}}$$



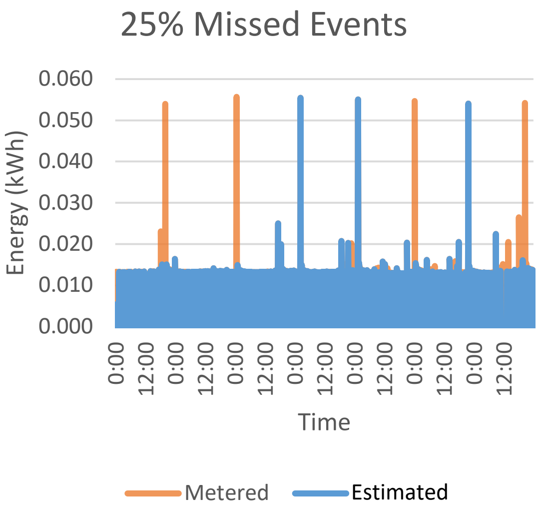
$\hat{E}_i$= Estimated energy @ each time interval
E_i= Metered energy @ each time interval

Data and Results

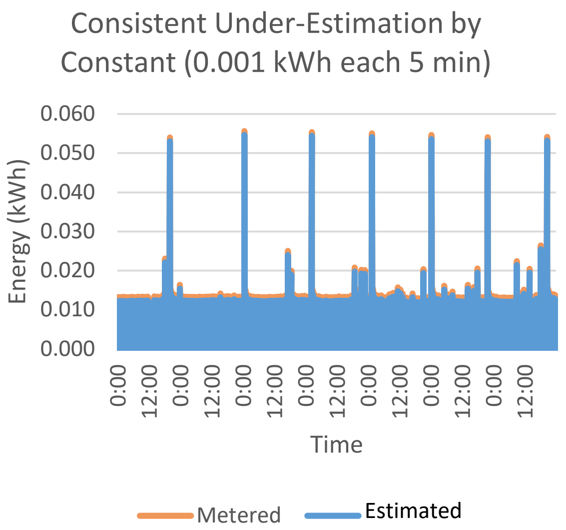
MR = 50%



MR = 70%



MR = 90%



Data and Results

Great	MR ≥ 70%
Fair	50% ≤ MR < 70%
Poor	MR < 50%
NA	not monitored or not disaggregated

Product A shows the most potential based on limited data

Match Rate – Overall

	Refrigerator	Dryer	Dishwasher	Cooking	Furnace	HVAC	Domestic Hot water	Clothes Washer
Product A	75.9%	76.8%	73.8%	32.2%	71.2%	7.2%	45%	52.6%
Product B1	49.1%	0.6%	10.6%	30%	NA	21.7%	9.9%	NA
Product B2	NA	37.8%	13.8%	16.6%	NA	15.3%	5%	NA

Great Performance

Based on only 1 home w/ gas cooktop & electric oven

Based on only 1 home w/ central AC
Heat pump not identified

Based on 1 home w/ electric water heater
3 homes w/ gas

Based on only 1 home
Not monitored in 2 of 4 homes

Data and Results

Product B has a promising product design, but communications reliability and accuracy are inadequate for large-scale disaggregation

	Advantages	Disadvantages
Installation	• < 1 hour • No electrician needed • Potential for participants to self-install	• Indoor + outdoor installation • Repeater or mesh network needed in some cases
Cost	• Lowest	
Maintenance	• Customer service is helpful	• Poor communication strength • Frequent participant engagement needed
Monitoring		• Does not ID all priority end uses • Difficult to map disaggregation to ground truth • Poor identification & accuracy

Data and Results

Product A demonstrated the most potential and warranted further investigation

	Advantages	Disadvantages
Installation	• < 1 hour	• Electrician needed for typical person
Cost	• Reasonable cost	
Maintenance	• Occasional participant engagement needed • No major data losses after communication issues resolved	• Heavy bandwidth consumption • Data lost if device offline > 8 hrs
Monitoring	• Easy to map to ground truth • Great and fair accuracy shown for several end uses • High sampling rate	• Installed in subset of homes (limited data sample)

Lessons Learned

Site Challenges	Best Practices
WiFi in Garages & Basements	• WiFi signal strength meter • WiFi repeaters added to three homes • Mesh network WiFi system • Validating online/offline devices • Protocol for re-establishing communications
Shared & Mislabeled Circuits	• Identify inactive circuits • Testing of end uses on circuits • Collect model numbers • Plug load monitors

Next Steps – Phase II

Augment Phase I
• Install Product A in the four homes without it • Remove the other disaggregation products from pilot • Revisit all homes to improve ground truth
Disaggregation of Higher-Frequency AMI Data
• Matched pair of AMI data and ground truth data • Analyze the ground truth data for baseline • Partner with vendor(s) to disaggregate AMI data • Compare disaggregation results with ground truth

Conclusions

- Homeowner acceptance, communications reliability, cost, and accuracy varies between load disaggregation products
- One of the three load disaggregation products demonstrated strong potential to support EIA, and therefore merited further evaluation in Phase II
- Other two products have unique characteristics that may serve consumers with different priorities
- Over the long term, AMI data disaggregation may offer a scalable, cost effective solution for understanding end-use energy consumption

Q&A

Bill McNary
Energy Information Administration
Ph: (202) 586-6828
William.McNary@eia.gov

Ebony Mayhorn
Pacific Northwest National Laboratory
Ph: (509) 372-4468
Ebony.Mayhorn@pnnl.gov

Josh Butzbaugh
Pacific Northwest National Laboratory
Ph: (971) 940-7092
Joshua.Butzbaugh@pnnl.gov