BEST
Building Efficiency for a Sustainable Tomorrow

2023 Annual Institute

Building Technician Education in a Time of Challenges & Innovation

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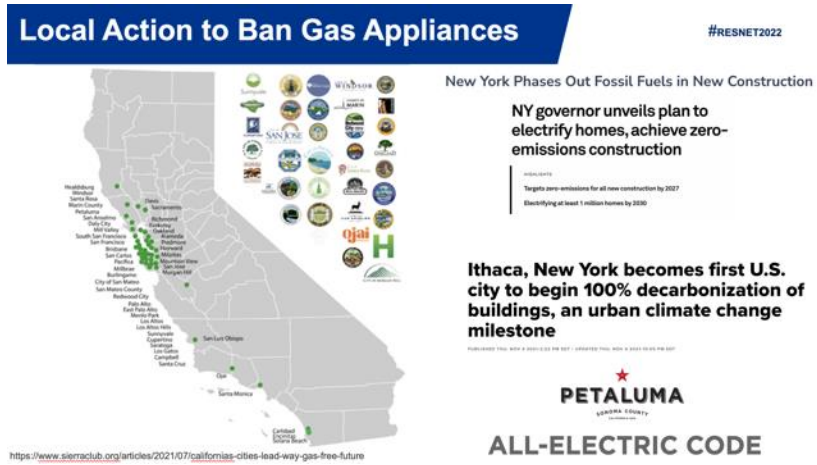
Iain Walker

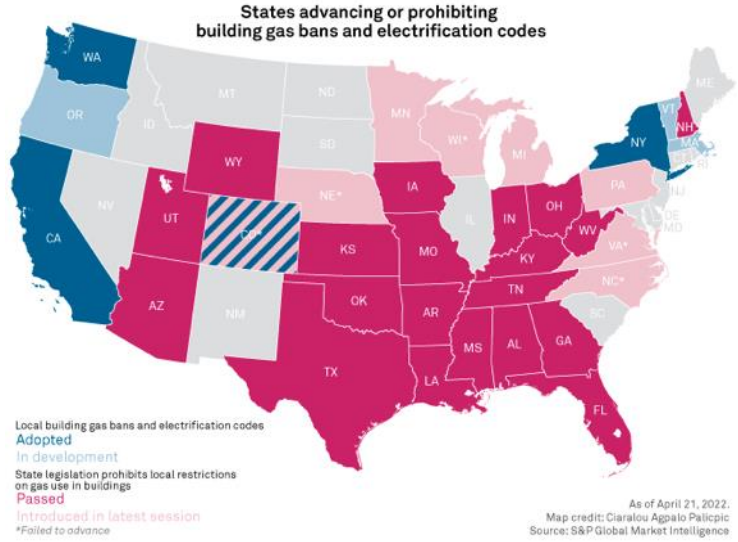
Staff Scientist, LBNL

“Avoiding Electric Panel and Service Upgrades in Home Decarbonization”

Retrofit focus

- New homes already energy efficient and increasingly all-electric
  - CA no longer subsidizing expansion of natural gas distribution system to new buildings
  - Some local authorities requiring/encouraging all-electric new construction
- New homes almost always have enough panel capacity – 200A typical
- *How do we minimize the cost to electrify existing homes???*





Panel Upgrade Costs

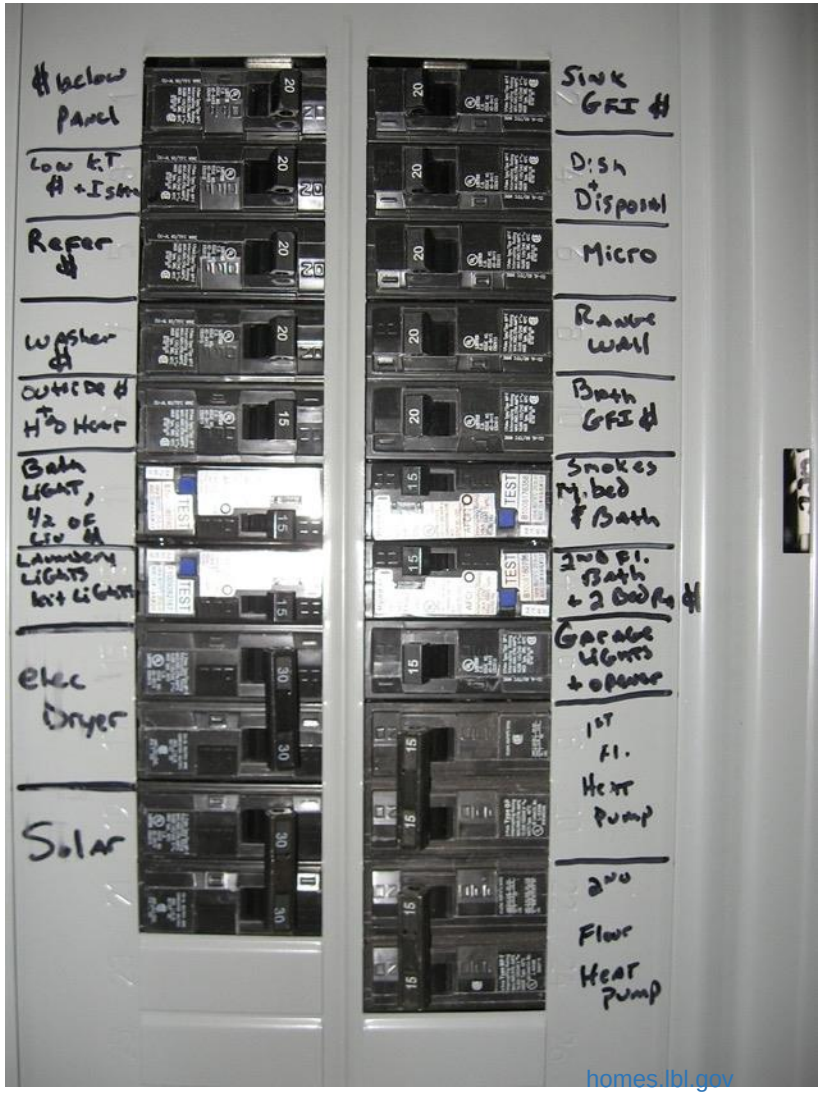
$1,954

Average range: **$1,500 - $4,000**

Low	Average Cost	High
$800	$2,500	$4,500

(replace an existing panel with a new model with new housing)

- Add ~$250-500 for each new circuit
- Add $300-$30,000 for service upgrades
- Big increases in past couple of years (>20%)
  - Material costs
  - Everyone is busy
  - New codes can require moving panel
  - Currently panel replacement + service upgrade is $6,000 in CA Bay Area
  - Long wait for electricians and utility service
- Currently driven by PV and EV additions



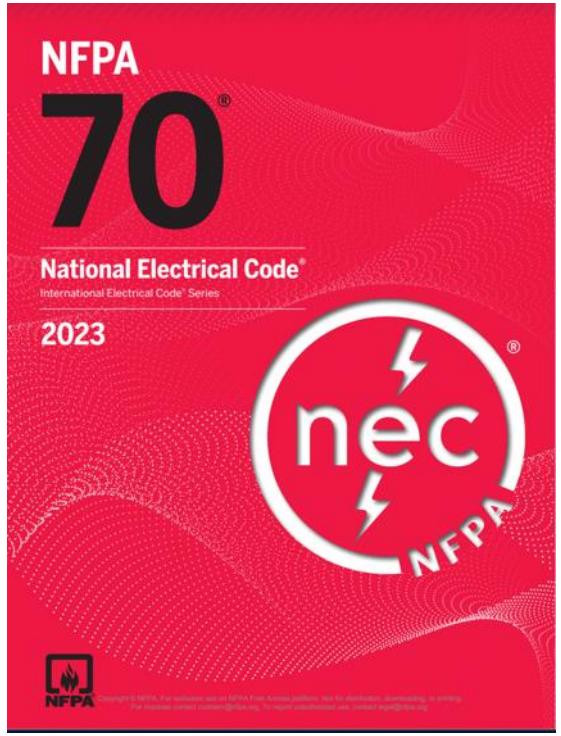
homes.lbl.gov

Avoiding redecorating

Photo – Eric Morill

Potential Solutions

- Alternative paths in the National Electric Code
- Updating codes and standards to better accommodate home electrification
  - What are actual coincident loads
  - How close are most homes to panel capacity and ability to add loads
  - Understanding equipment limits
- Load reductions/load control
  - Power Efficient Appliances
  - Circuit Sharing
  - Energy storage
  - Focus on large loads: Heating/Cooling, DHW, Clothes Drying, Cooking, PV & EV



NEC Options

NEC 220.87

- Existing loads based on metering data (15 minute)
- Total load = (Metered Load) x 1.25 + New Load

NEC 220.83

- Existing loads as a bottom-up summation of connected loads with different treatment when adding HVAC
- No New HVAC: 8,000 watts + 40% of remaining connected loads (including heating and cooling)
- New HVAC: 8,000 watts + 40% of remaining connected loads + max(heating, cooling)

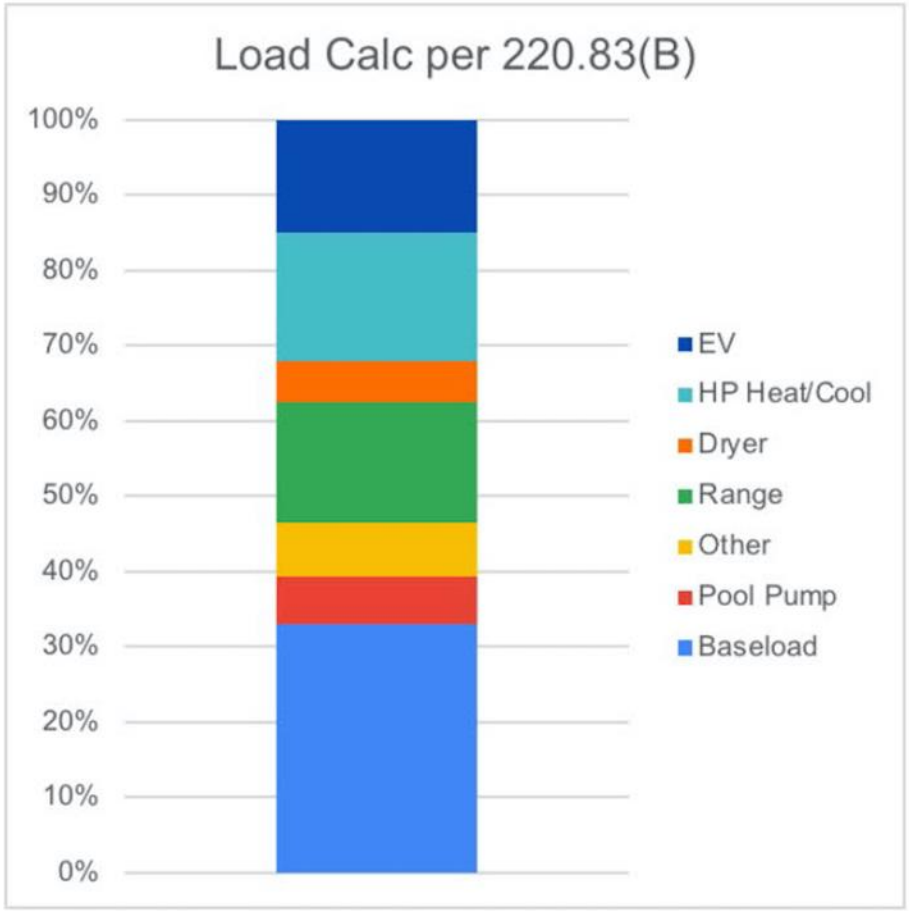
Panel Sizing Method Improvements?

- Better estimate load coincidence
- Allow for load management, circuit sharing, storage technologies, etc.

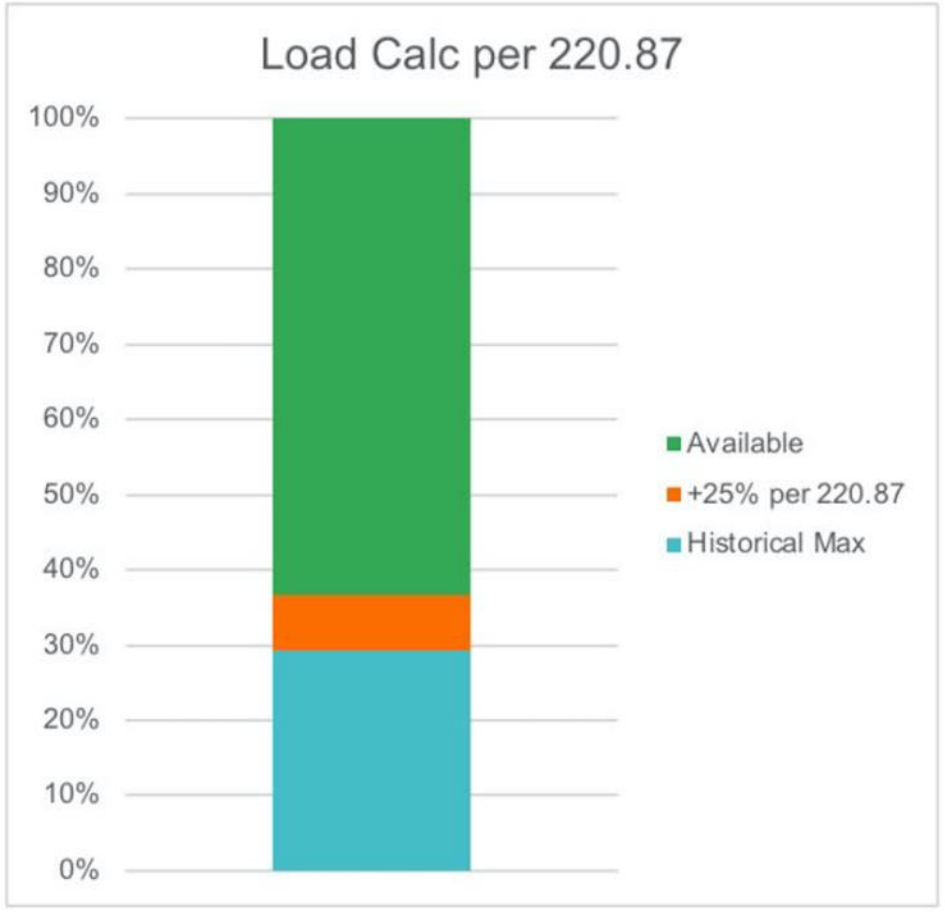
Comparison of load calculation options

Same house: Calculations using both 220.83(B) and 220.87

from Josie Gaillard



Per NEC 220.83(B): no room left for HPWH



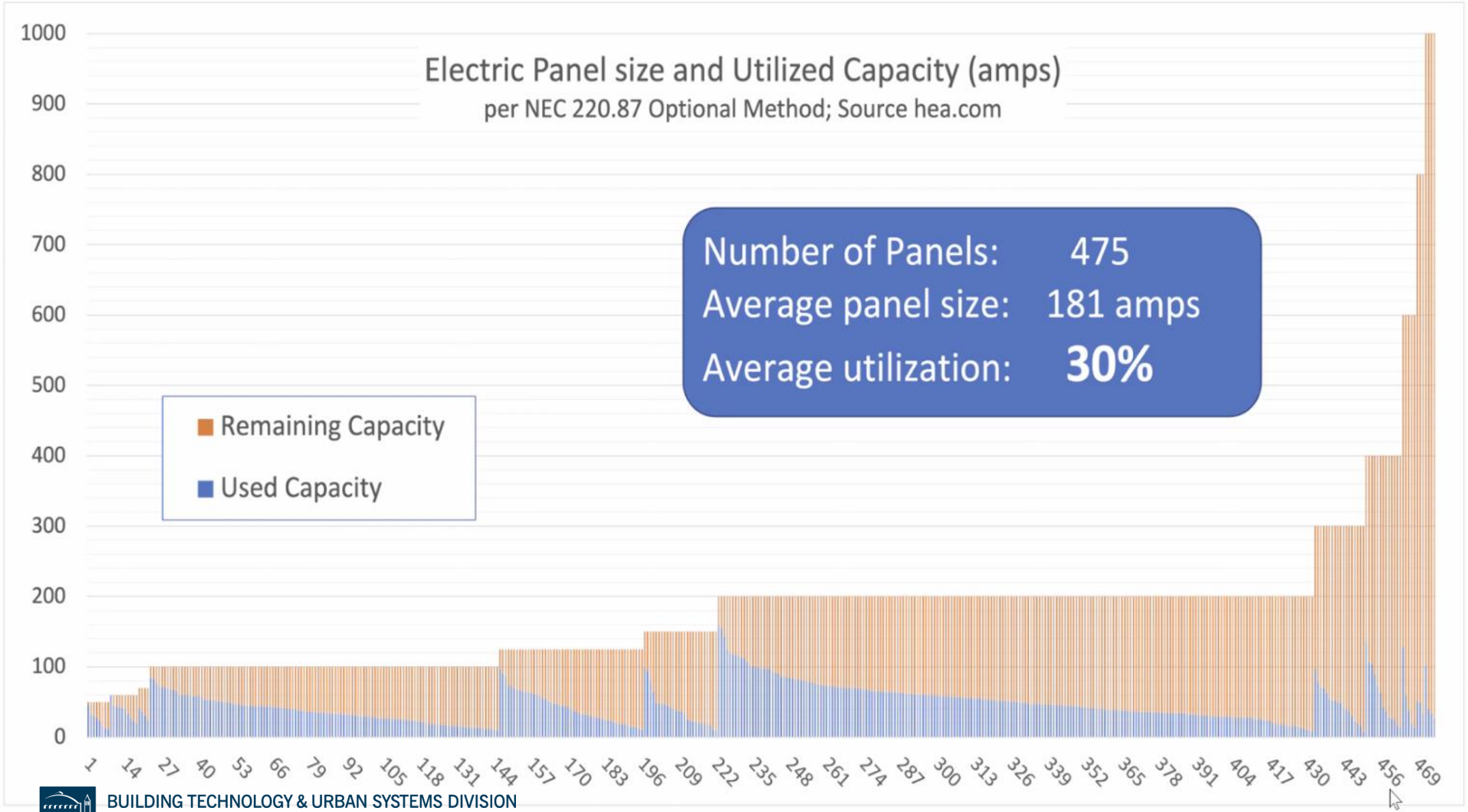
Per NEC 220.87: plenty of room for HPWH

120% rule for PV

PV Amps = Busbar Rating x 1.2 – Main Breaker rating
200A bus bar and 200A main breaker allows for 40A of PV

We can increase PV allowance by **decreasing** the main breaker rating
200A busbar and 175A main breaker allows for 65A of PV

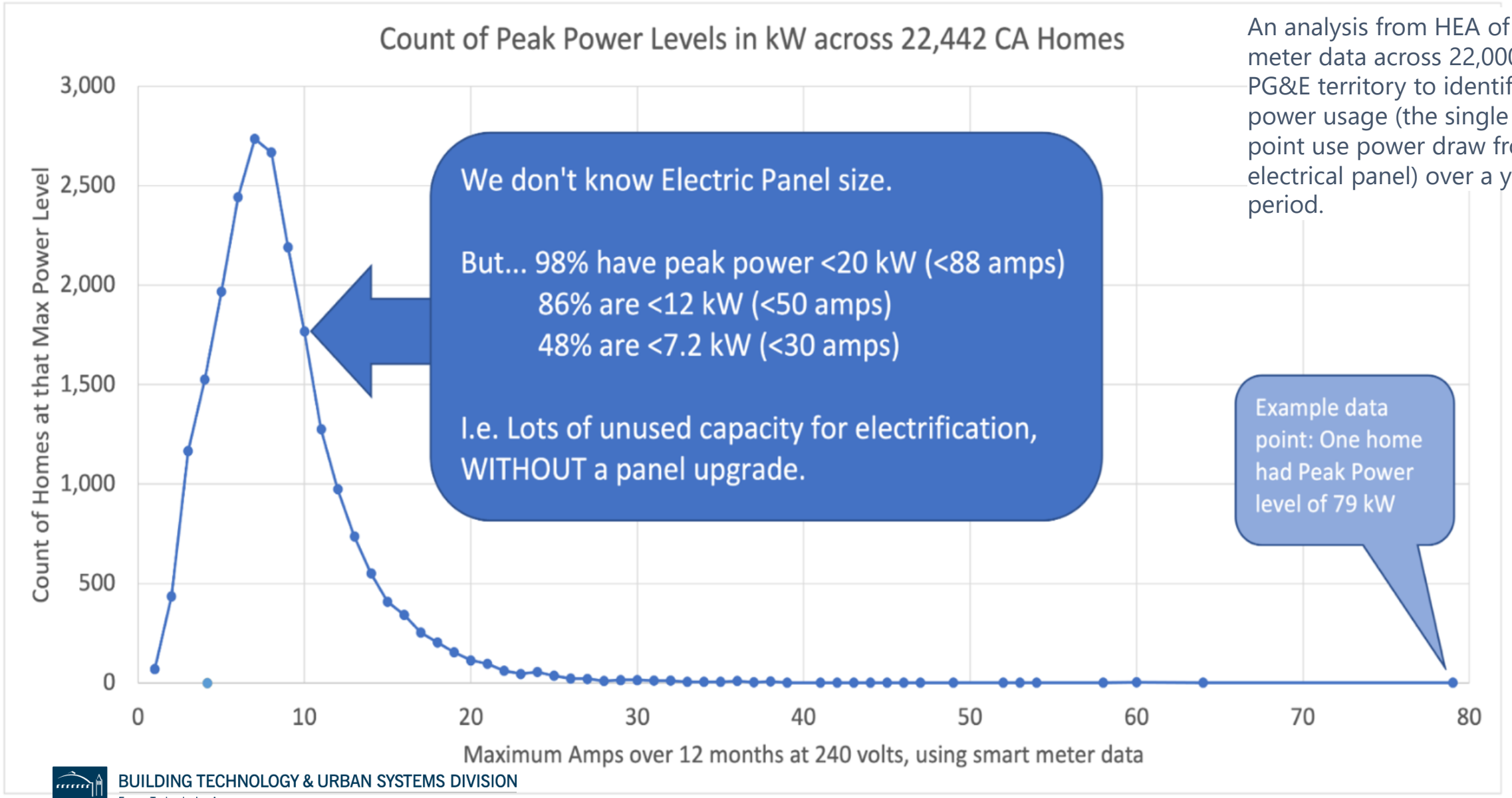
Available Capacity to Electrify



*Not a representative sample of all CA homes, and mix of all electric and electric + gas.

Source:
HEA, HomeIntel

Available Capacity to Electrify



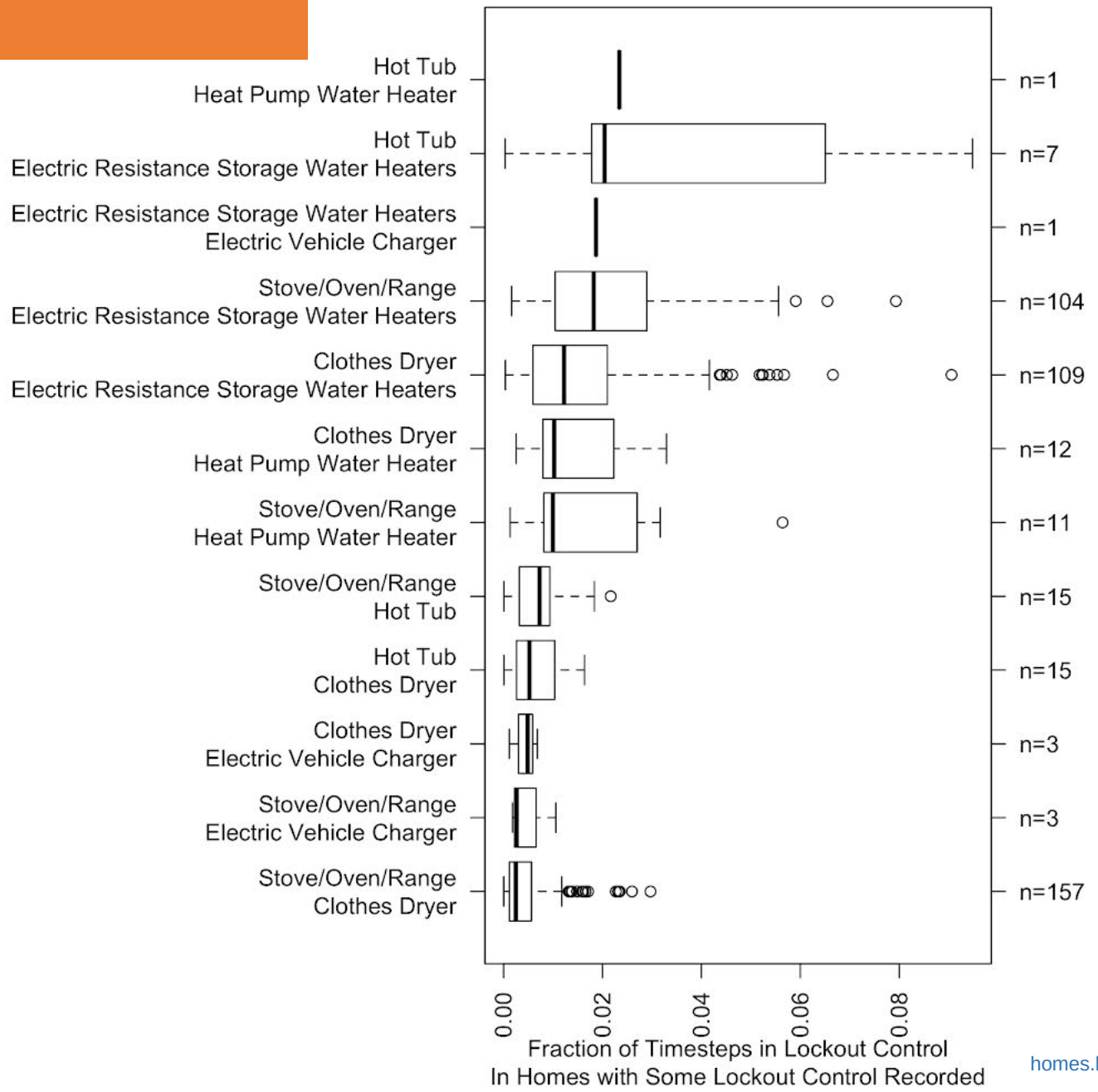
An analysis from HEA of smart meter data across 22,000 homes in PG&E territory to identify peak power usage (the single greatest point use power draw from their electrical panel) over a year-long period.

Source:
HEA, HomeIntel

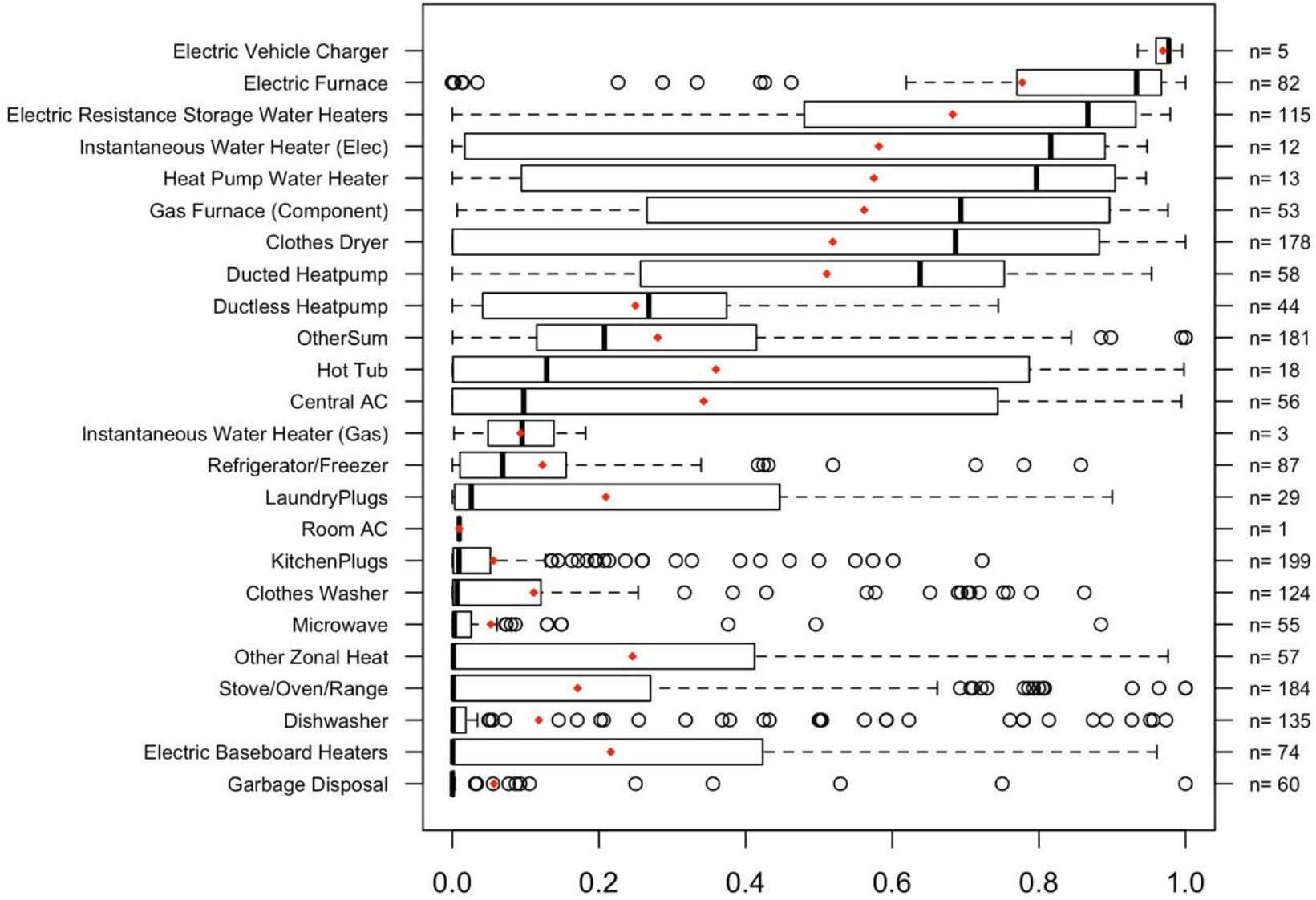
Circuit Sharing Potential

15 minute data from 1300 homes from NEEA study

If high power devices share a circuit how often would one have to be switched off?



How Much Does Each End Use Contribute to the *Home* Peak



End use load during home peak load/End use peak load

When the Home Peaks, the EV charger or Electric Furnace is on

When the Home Peaks, the plugs and many other loads are off

Utilizing the NEC – e.g., the Watt Diet Calculator

Watt Diet Strategies

Basic strategies for avoiding an electrical panel upsize can include:

01 - Select appliances that combine two functions into one machine

For example, the kitchen range (combining an oven and cooktop in one slide-in appliance), which lets us avoid a separate high power circuit for wall ovens. Another example is a combined washer/condensing dryer machine that lets us avoid needing a circuit for the clothes dryer.

02 - Select power efficient versions of the appliances

Choose the 15-amp version of a heat pump water heater instead of the 30-amp nearly identical version. Selecting high performance, power sipping versions of heat pumps instead of lower performance versions. Select power efficient and energy efficient heat pump dryers if you want a separate clothes dryer.

03 - Reduce heat loss and cooling loss by insulating and air sealing

04 - Use prioritized circuit sharing devices

These handy devices can automatically pause car charging while other appliances, like the dryer, finish.

05 - Use EV charger pausing circuits

These briefly pause EV charging if many devices are on at once and the main breaker is at risk of popping.

06 - Avoid overkill in your EV charger settings.

For example, pick a 20-amp or 30-amp outlet for your EV charging and avoid 50-amp chargers at home. A 20-amp outlet can deliver 100 miles of charge overnight and more than 50,000 miles of charge in a year. Bigger car batteries don't require bigger circuits; they give you flexibility about when you charge.

https://www.redwoodenergy.net/watt-diet-calculator

All Electric 100 Amp Home (2,000 square feet)

Ducted heat pump, medium power heat pump water heater, hybrid heat pump dryer

Device Volts	Device Amps	100 Amp Panel		Device Amps	Device Volts
120	8	Lights/Plug 15	15 Lights/Plug	8	120
120	8	Lights/Plug 15	15 Lights/Plug	8	120
120	8	Lights/Plug 15	15 Lights/Plug	8	120
120	10	Garbage Disposal 20	20 Kitchen Outlets	13	120
120	7	Refrigerator 20	20 Kitchen Outlets	13	120
120	0	Spare 15	20 Dishwasher	12	120
120	0	Furnace (removed) 15	20 Clothes Washer	13	120
240	20	Heat Pump Centrally Ducted 30	20 Hybrid Heat Pump Dryer	14	240
240	20	EV Charger 25	50 Range (cooktop +oven)	40	240
240	16	Solar Input 20	20 Heat Pump Water Heater	12	240

House square footage = 2000 Total Counted Panel Amps = 96.7

Source - Tom Kabat & Sean Armstrong

New products coming to the industry

Smart Circuit Splitters and Sharing

EV-PowerShare[xlii]
EV-PS Smart

SimpleSwitch[xliv]
240V / EV Circuit Switch

BSA Electronics[xli]
Dryer Buddy

Neo Charge[xlii]
Smart Splitter

Programmable Subpanels

Eaton[xxxix]
Energy Management
Circuit Breaker (EMCB)

Power-efficient Appliances (120V)

4.5 cu ft Condensing Washer/Dryer Combo	Heat Pump Water Heater	Through-Wall Heat Pump
10A, **1200W**	8.3A, **1000W**	6.3-15A, **~1400W**
LG WM3998HBA	GE GeoSpring	Innova HPAC 2.0
		

Battery Integrated Stoves

Meter Collars

Conventional "Efficient" Appliances (240V)

Product Type	Electric Dryer-Energy Star	Heat Pump Water Heater	Split Heat Pump 2-4 Tons
Maximum Rating	30A, **7,200W**	19A, **4,500W**	18-29 Amps, **4,300W-7,000W**
Make and Model	Whirlpool WED5620HW	Rheem Prestige	York YZH060 Series
Image			

Power Efficient Appliances (120V)

Power at the panel is the limiting factor, but reducing appliance voltage can be another strategy

Product Type	4.5 cu ft Condensing Washer/Dryer Combo	Heat Pump Water Heater	Low-Amp Window Heat Pump	120V Mini-Split Heat Pump
Maximum Rating (Amps, Watts)	10A, **1200W**	8.3A, **1000W**	6.3-15A, **~1400W**	10.4A, **1090W**
Make and Model	LG WM3998HBA	GE GeoSpring	Innova HPAC 2.0	LG LS-120HXV
Image				

Power Efficient Appliances Example Calculation

Typical Energy Efficient Appliance		Power Efficient Appliance	
Device	Power (W)	Device	Power (W)
2 ton Heat Pump	4,400	120V minisplits	1,100 (x2?)
Water heater	4,500	120V HPWH	1,000
Clothes Dryer	7,200	120V HP washer/dryer	1,200
Range	9,600	120V 2-burner cooktop and 120V Countertop Oven	1,200 1,200
EV charger	7,200	EV-pauser/circuit sharer	0
Total	**32,900**		**5,700**

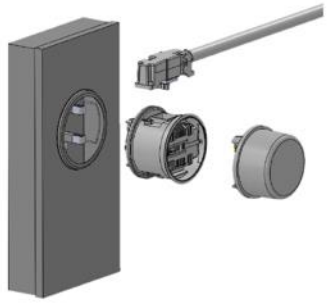
Meter Collars bypass internal busbar current limit

EXISTING PRODUCT - SOLAR

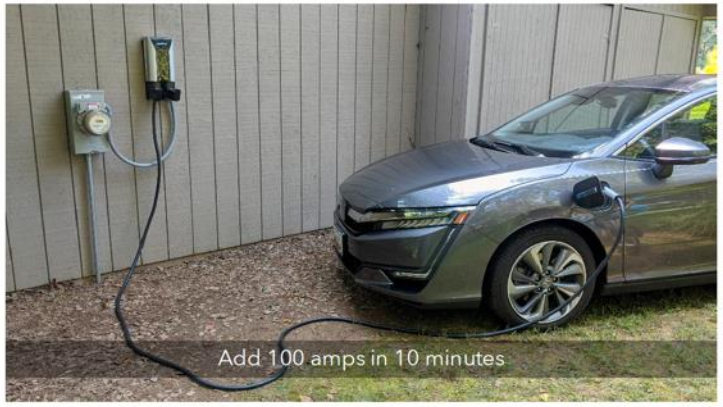
- Solar Adapter
  - UL Listed (414 - Meter Sockets)
  - 5 mins to install, 30 mins to interconnect
  - 200A continuous rating, utility power
  - 80A continuous rating, PV input (15kW)
  - Integrated PV breaker
  - Optional smart module – RGM and cellular comms
  - Approved in 20 states
  - 15,000 units installed

WE TURNED THE METER SOCKET INTO AN ELECTRICAL OUTLET

Our simple, affordable, and universal meter adapter works on virtually every home and eliminates the need for service panel connections or replacements



Plug-in adapter uses meter socket instead of the service panel



Peak Reduction Using Storage

Can be charged from onsite solar or low-cost mid-day grid power – saves $

Good for disadvantaged/low income communities: avoid peak pricing and demand charges

Electric Battery

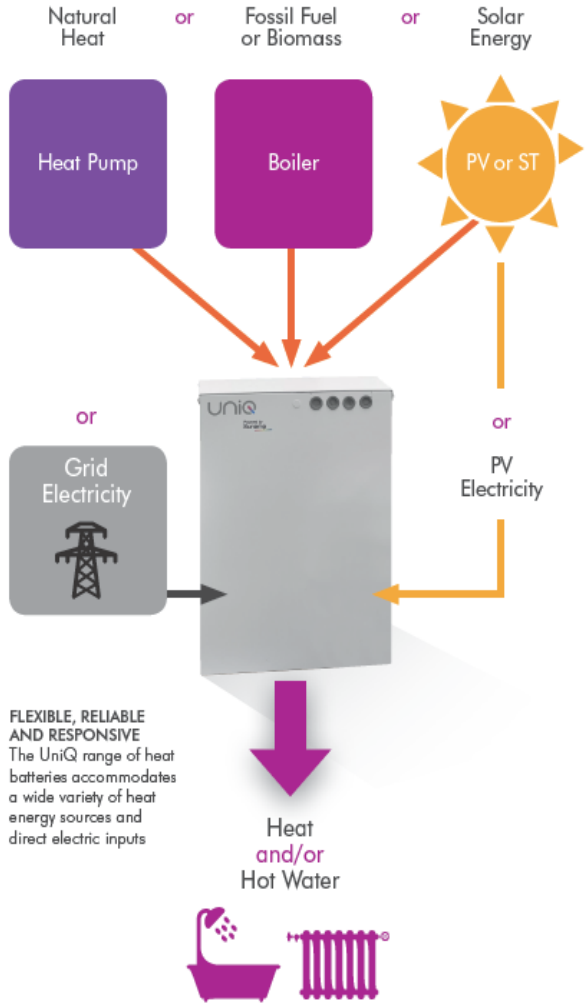
- 3 to 5 kWh
- Smaller for individual appliances

Thermal Storage

- Safe, common, phase change materials
- 10.5 kWh in same space as 50 gallon tank

Reduce Peak

- 1000W from storage + 1000W from grid to power a 2000W heat pump



Integrating transportation

- Current poor public charging infrastructure:
  - Need to be able to charge at home
- EV could easily be the biggest home load: up to 50 kW
  - Need to restrict power requirement to 7.2kW
  - Encourage low-power charging – good for most households
  - Use timers/smart circuit sharing/meter collars

New ideas?

American-Made Challenges

2,764 Share Follow (97)

EAS-E Prize

Supports design solutions, tools, and/or technology innovations that make electrification more affordable and accessible in U.S. homes.

Energy, Environment & Resources | Government | Technology

Stage: **Enter**

Prize: **$2,400,000**

SOLVE THIS CHALLENGE

Summary | Timeline | Updates 2 | Forum 4 | Teams 97 | Resources | FAQ

Overview | Guidelines

Challenge Overview

The Equitable and Affordable Solutions to Electrification (EAS-E) Home Electrification Prize provides up to $2.4 million in prizes for innovative solutions that advance electrification retrofits of residential homes across all building types and geographies.

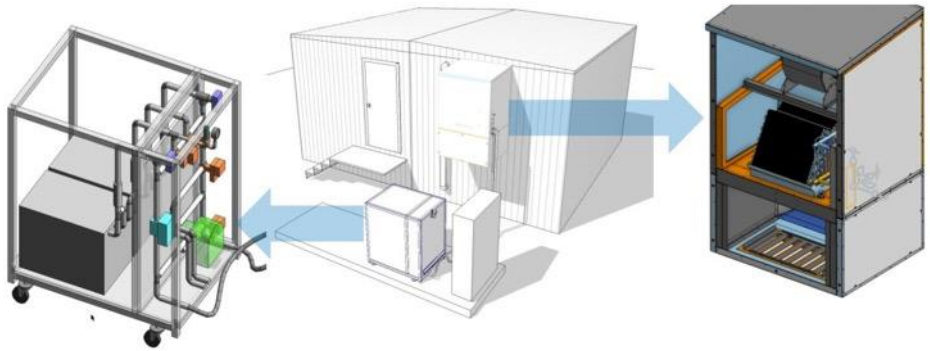
New Ideas?

- Analyzing electrification without panel upsizing: how many homes, what are peak loads?, NEC changes, etc…

- Using thermal storage to boost capacity so lower power lower capacity heat pumps can be used = grid responsive HVAC

- Cold Climate heat pumps (avoiding high power electric resistance backup)

1. Characterize the Problem	2. Characterize Current Solutions	3. Solution Development and Validation	4. Techno-economic Analysis	5. Market Transformation
• Citizen science panel survey • Data-driven peak load analysis • Model-based national scale analysis (ResStock) • Industry data gathering	• Evaluate the functionality and cost of existing solutions • Assess potential of load control • Field survey and workforce outreach	• Architecture design • Development of the digital capacity management solution • Possible paths to market	• Framework for analysis at the building scale • Scale up to the U.S. residential building stock • Estimate impact of NEC revisions • Dissemination	• Proposed changes and interpretation of the NEC • Development of resources and tools for homeowners, code officials, and practitioners
POP: Q1—Q3	**POP**: Q2—Q4	**POP**: Q3—Q7	**POP**: Q4—Q8	**POP**: Q6—Q8



U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Residential Cold-Climate Heat Pump Technology Challenge

Rethinking Rebates?

- Currently $2500 for a panel upsize (IRA up to $4000 + $2500 for additional wiring)
  - Allows high power devices and higher peak load from home to utility
  - New distribution and transformer upsizing.\
  - These costs passed on to ratepayers
- Include rebates for ***avoiding*** panel replacement
  - 120V HPWH
  - Small split HP systems
  - 120 V cooking
  - Battery systems (whole home or in appliances)
  - EV pausers
  - Meter collars

Summary

- Use existing NEC options (with guidance available online)
- Use power efficient equipment – preferably 120V
- Use circuit sharing – particularly for EVs (most “pauseable” load)
  - Consider lower power EV charging
- Meter collars allow quick addition of big loads
- Traditional load reduction helps (lower capacity heating/cooling equipment)

In the (near) future

- Storage technologies at whole house and individual appliance level
- Updated NEC to allow new technologies & improve existing calculations
- More resources to guide contractors and homeowners becoming available
- More power efficient options

Resources

- For electrification big picture: **Rewiring America** and **Rewiring Communities**
- For power-restricted homes: **Redwood Energy Pocket Guide**
- Check with your contractor or utility for rebates

Rewiring Communities:

A Plan to Accelerate Climate Action and Environmental Justice By Investing in Household Electrification at the Local Level

[1] Adam Zurofsky,[2] Jeffrey Schub,[3] John Rhodes,[4] Tony Curnes,[5] and Sam Calisch[6]

REWIRING AMERICA

Coalition for Green Capital

Resources

All-electric retrofit guides and the **Watt Diet calculator** from Redwood Energy: https://redwoodenergy.net/all-electric-retrofits/

Smart grid technologies — Rewiring America

Load sharing & related devices — Canary Media

PG&E class on How to electrify without upgrading your panel

Building Electrification Institute

www.zerocarbon-home.com

Electrification Retrofit Consultants & Contractors in California

There are many, but here are a few to get you started:

- All-Electric California
- Electrify My Home
- QuitCarbon
- and many others at the **Switch Is On Contractor Directory**: https://switchison.cleanenergyconnection.org

Questions?

Extra slides

Breaker curve

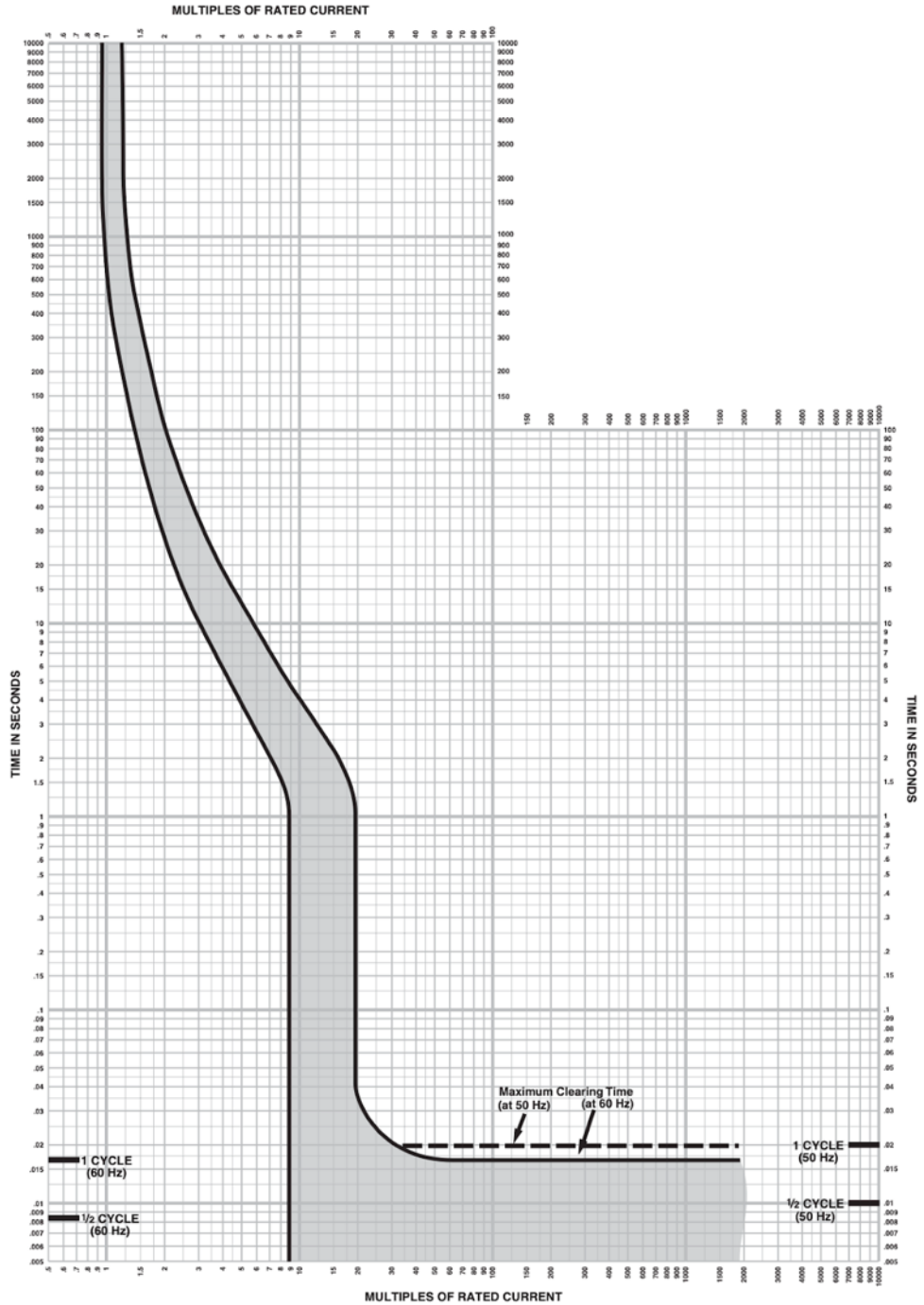
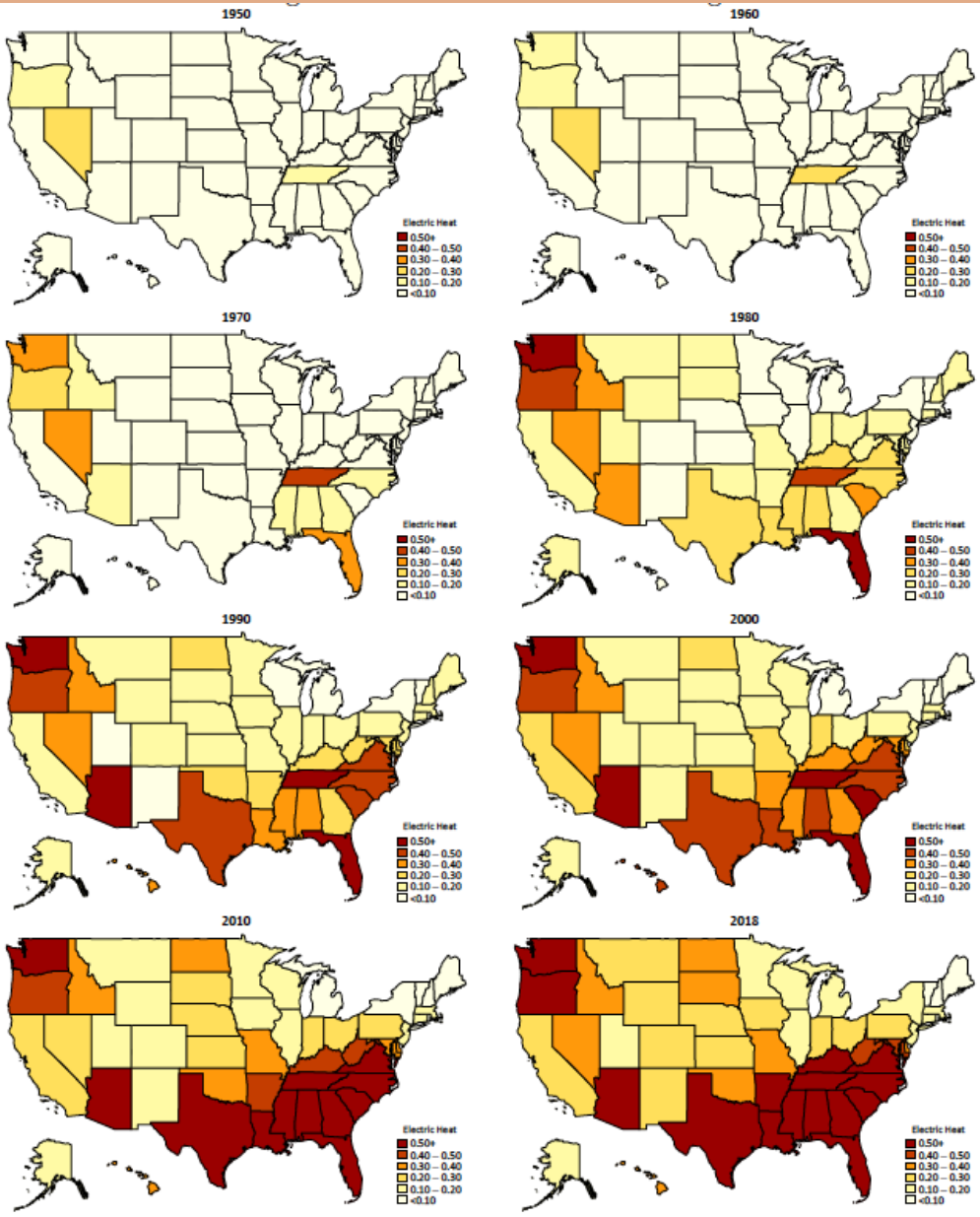


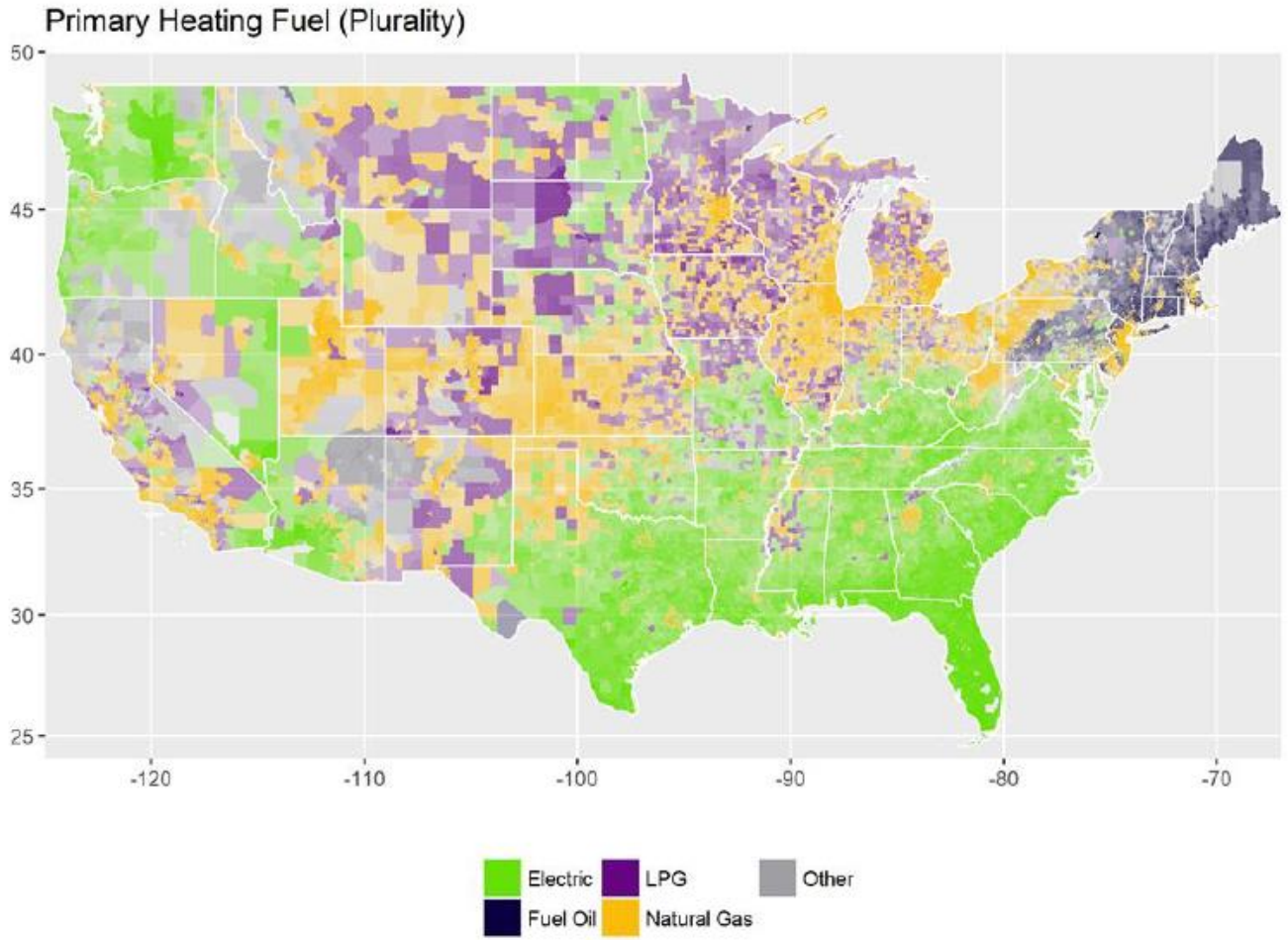
Figure 1: Thermal-magnetic Time/Current Characteristic Curve

Electric Heating

Growth in Electric Heating



Distribution of Electric Heating



Data from the American Community Survey (2016).

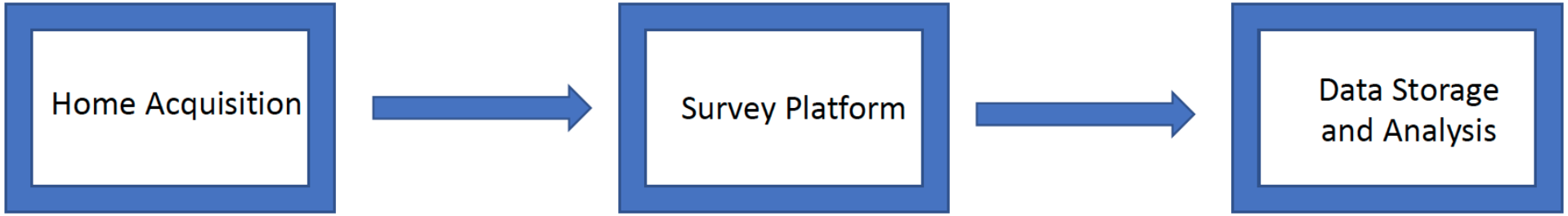
- 40% of homes have electric primary heating
- >25% of homes are already all-electric
- 75% of homes have central AC

Tips for avoiding an expensive electric panel upgrade:

- Consider sharing existing 240V circuits between two devices using a "smart splitter" like those from NeoCharge,SplitVolt and DryerBuddy.
- To free up old 240V circuits, upgrade to more efficient appliances, such as a combined 120V washer dryer, akitchen range that combines an induction cooktop with an oven on a single circuit, or replacing a 240 volt ovenwith a plug in air fryer, instapot, or other combined device.
- Consider a load monitoring device to "throttle" EV chargers to available household power, such as the SimpleSwitch or DCC-9 devices.
- Limit EV charging. Note that most EVs will gain over 40 miles of range after 10 hours of charging on a standard120V outlet. This satisfies most commutes, and longer trips can be handled via the growing network of public DCfast-charging stations.
- If you are considering a panel upgrade see this related report by PG&E and others.
- Plan in advance for future loads using the table below, like EV chargers, heat pumps, and induction cooktops. Ifpanel capacity is limited, spend more for the most efficient versions of each appliance since it can avoid muchmore expensive panel upgrade costs.

Citizen Science

Approach to Acquiring Data on Panel and Home Characteristics



Amazon Mechanical Turk **Survey Monkey** **Google Sheets**

Citizen Science

Survey Questions (1)

The Worker sees this survey form

* 1. Please select the type of single family home you live in (if you do not live in a single family home, we kindly ask that you do not fill out this survey and stay tuned for another survey)

- ○ Single-family detached
- ○ Single-family attached

* 2. What state do you reside in?

* 3. What city do you reside in?

* 4. What is your 5-digit zipcode?

* 5. What is the approximate year your house was constructed?

* 6. What is your home's approximate floor area? (in square feet)

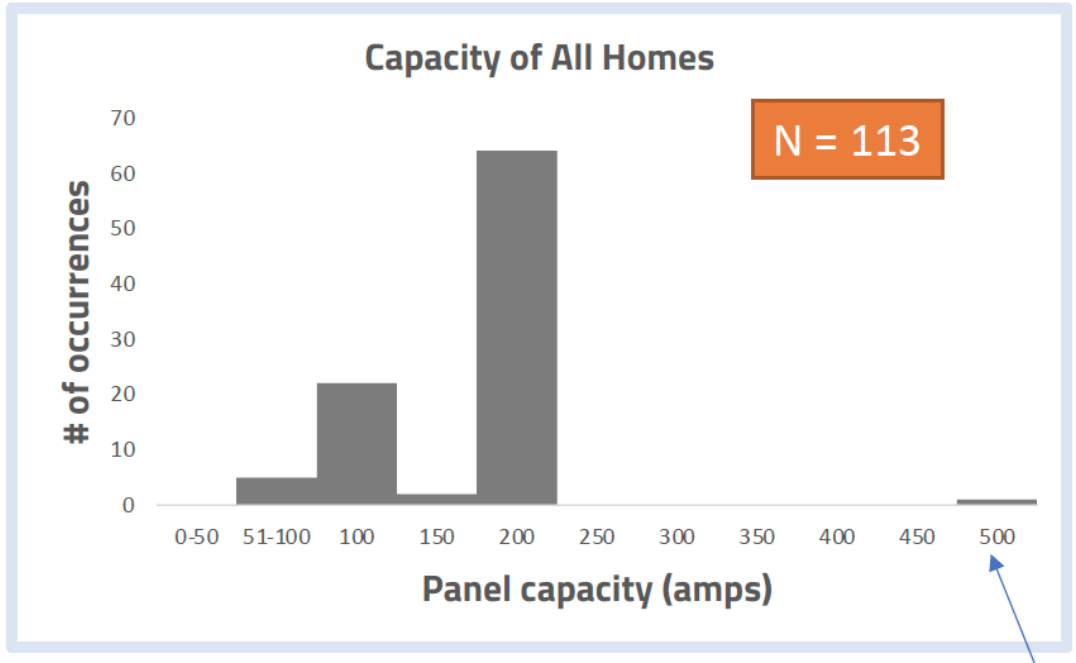
Summary of Questions

- Location (state, city, zip code)
- House year of construction
- Electric appliances in house
- Gas appliances in house
- 2 photos of electrical panel
- Input value of panel capacity (between 20-1000)

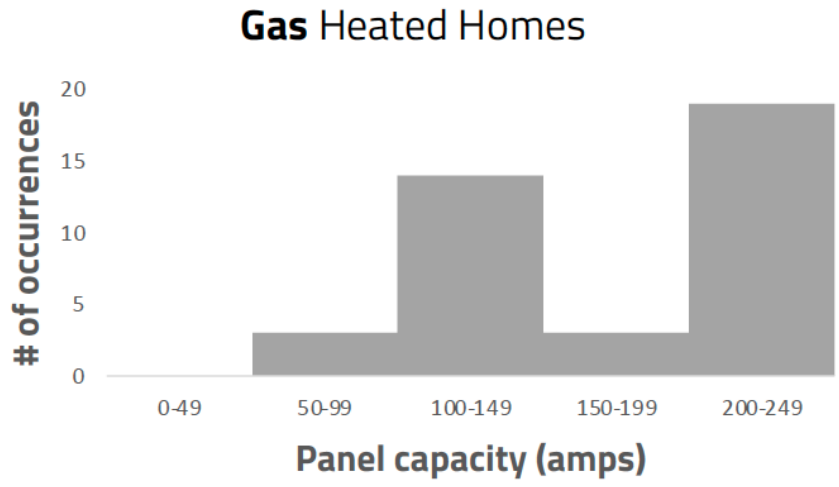
* 7. Please select all major electric appliances that you use in your home

- ☐ Central air conditioner
- ☐ Room air conditioner
- ☐ Heat pump
- ☐ Electric resistance space heating
- ☐ Electric stove/range/oven
- ☐ Electric water heater
- ☐ Electric clothes dryer
- ☐ Electric vehicle and charger
- ☐ Electric fireplace
- ☐ Electric heater for spa or pool
- ☐ Photovoltaic (PV) panels
- ☐ Battery storage for PV
- ☐ Well pump or pool pump
- ☐ Other (please specify)

Panel Capacities – Early Results



Bug?



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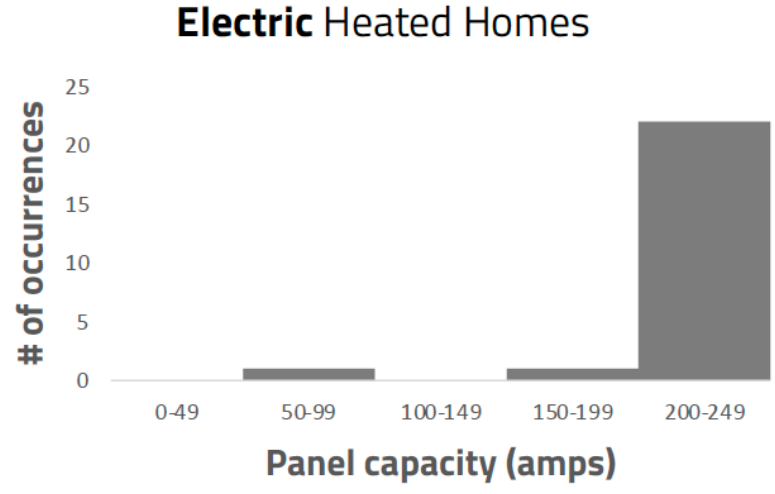

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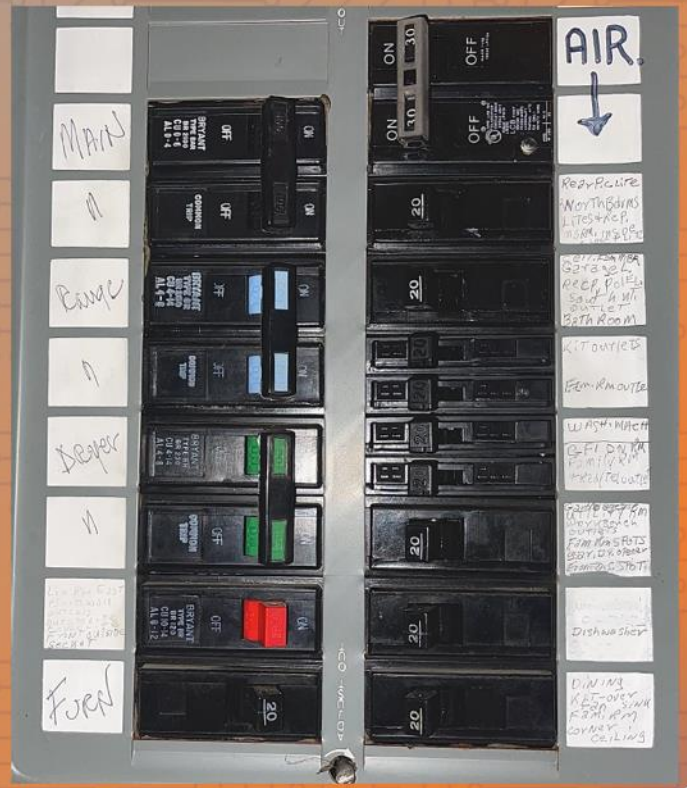
Citizen Science

Respondent Photos - Real

Note unused slots



Findings About Costs - Homeowner Side

"Homeowner Equipment Service Upgrade Fee" refers to the electrical panel and associated work behind the meter

Cost Description	Average cost	Transaction
Homeowner Equipment Service Upgrade Fee	$1,300 - $5,000	Homeowner → Contractor
Breaker Panel Upgrade	$1,300 - $5,000	Homeowner → Contractor
Upgrade/New Branch Circuits	$250 - $700 per circuit	Homeowner → Contractor
Permit Costs	**PG&E Territory**: $125 - $500 **Arcata, CA**: $129 **Humboldt County**: $132 **Other Northern Counties**: $125 - $140 **SDG&E Territory**: City $128, County $136	Homeowner → Contractor — OR — Homeowner → City/County
	Contractor "Bundled" Fee: $500 (All Permit + Labor Fees in one)	Homeowner → City/County
Trenching & Conduit	$5 - $15 per linear foot (Homeowner Property)	Homeowner → Contractor

Activity 1: Identify typical costs and Activity 2: Identify/explain factors that impact these costs

1 Customer-Owned Equipment Upgrades

$3,000 to $18,000+

Cost Description	Average cost	Transaction
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Activity 1: Identify typical costs and Activity 2: Identify/explain factors that impact these costs

2 Contractor Bills Utility for Labor

$2,000 to $30,000+

Utility provides the materials

- Wire
- Conduit
- Pole changeouts
- Transformer upgrades

Cost Description	Average cost	Transaction
Transformer Upgrade	$6,000 - $8,000	Homeowner → Utility
Pole Replacement	$9,000 - $11,000	Homeowner → Utility
Total New or Upgraded Utility Equipment Service	$10,000 - $30,000	Utility → Contractor
Overhead line, service line only	$2,850 - $4,500 (Utility supplies materials)	Utility → Contractor
Overhead line with a new Utility pole	$11,000 - $13,000 (Utility supplies materials)	Utility → Contractor
Overhead to underground conversion	$13,000 - $18,000 (Utility supplies materials)	Utility → Contractor
Trenching for underground upgrades	$180 to $200 per llinear foot (Utility/Public Property)	Utility → Contractor

All costs that exceed the Rule 15 and 16 allowance are passed on to the customer for the service upgrade

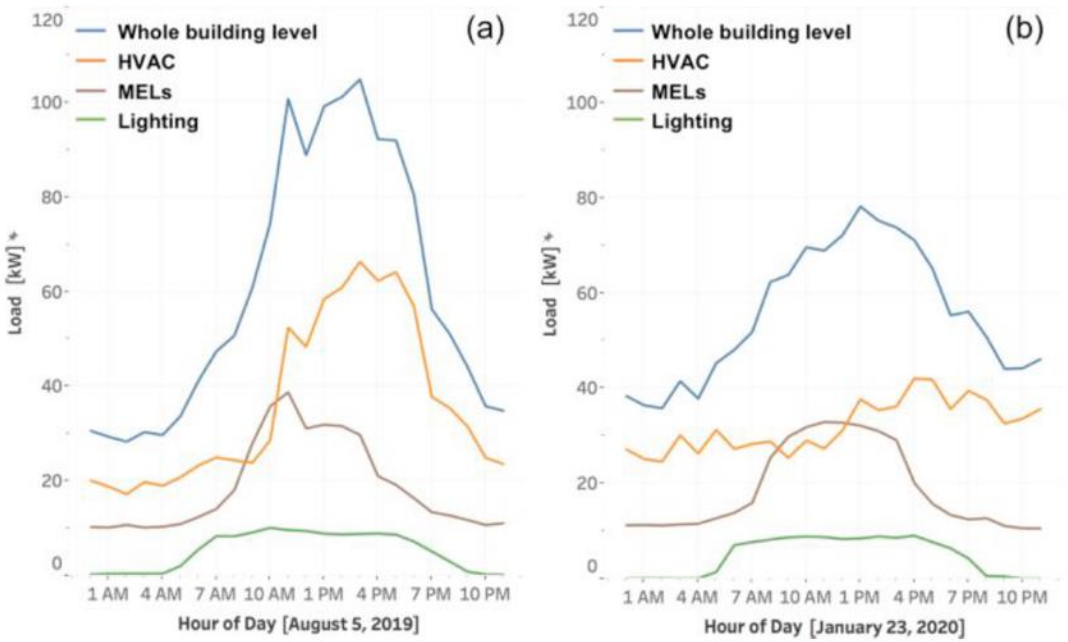
Utility Equipment Costs that the Customer May Pay

Cost Description	Average cost	Transaction
Transformer Upgrade	$6,000 - $8,000	Homeowner → Utility
Pole Replacement	$9,000 - $11,000	Homeowner → Utility
Total New or Upgraded Utility Equipment Service	$10,000 - $30,000	Utility → Contractor
Overhead line, service line only	$2,850 - $4,500 (Utility supplies materials)	Utility → Contractor
Overhead line with a new Utility pole	$11,000 - $13,000 (Utility supplies materials)	Utility → Contractor
Overhead to underground conversion	$13,000 - $18,000 (Utility supplies materials)	Utility → Contractor
Trenching for underground upgrades	$180 to $200 per llinear foot (Utility/Public Property)	Utility → Contractor

From Sean Murphy

The electrical code makes it hard to avoid a panel upgrade

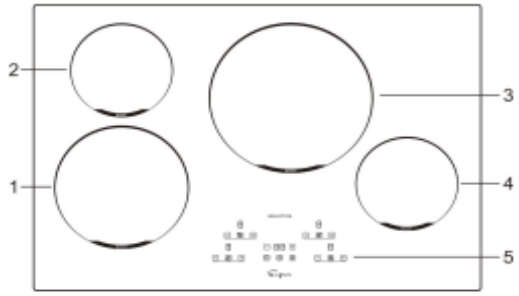
- The California Electrical Code encourages conservative panel sizing
  - Section 220.83 Existing Dwelling Units
  - Section 220.87 Determining Existing Loads
- Panel sizing methods
  - Overestimate the number of loads that coincide
  - Not designed for electrification retrofits
  - Do not permit load management



Credit: Luo et al 2022

20A Induction Range Design Test CalFlexHub Project

- Design a fully functional 20A range
  - Normally requires 40A circuit
  - Use power sharing
- LBNL experiments
  - Test existing induction cooktop and oven
  - Measure power consumption and switching pattern in various modes
  - Test loaded and unloaded
- Create common use cases and specs that dictate how to best design the product

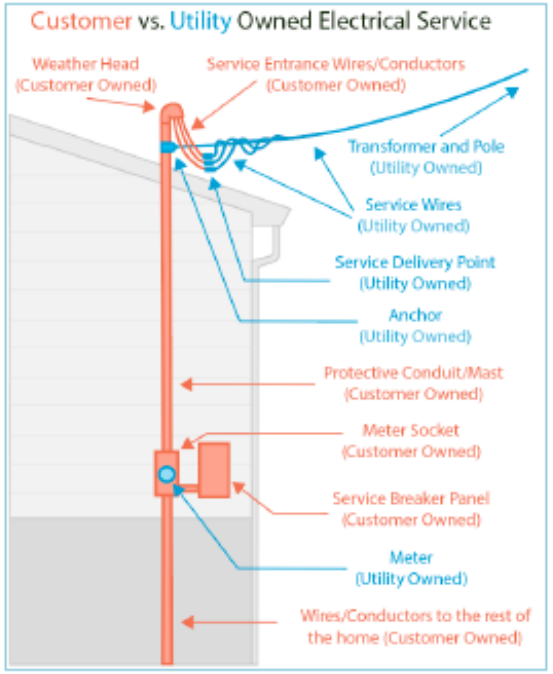


EMPV-30EC02

1. max. 1800/2100W zone
2. max. 1200/1500W zone
3. max. 2300/3700W zone
4. max. 1200/1500W zone
5. Control panel

Service Upgrades for Electrification Retrofits Study Final Report

May 27, 2022



Courtesy of Emily Higbee, Redwood Energy Research Director

The above image displays ownership of basic electrical service equipment that will be assessed by an electrification retrofit contractor to complete an overhead Service Upgrade. All the components depicted in the diagram are within the scope of an electrical Service Upgrade discussed in the report except for new wires to the rest of the home.

CALMAC STUDY ID: **PG&E0467.01**

N|V|5

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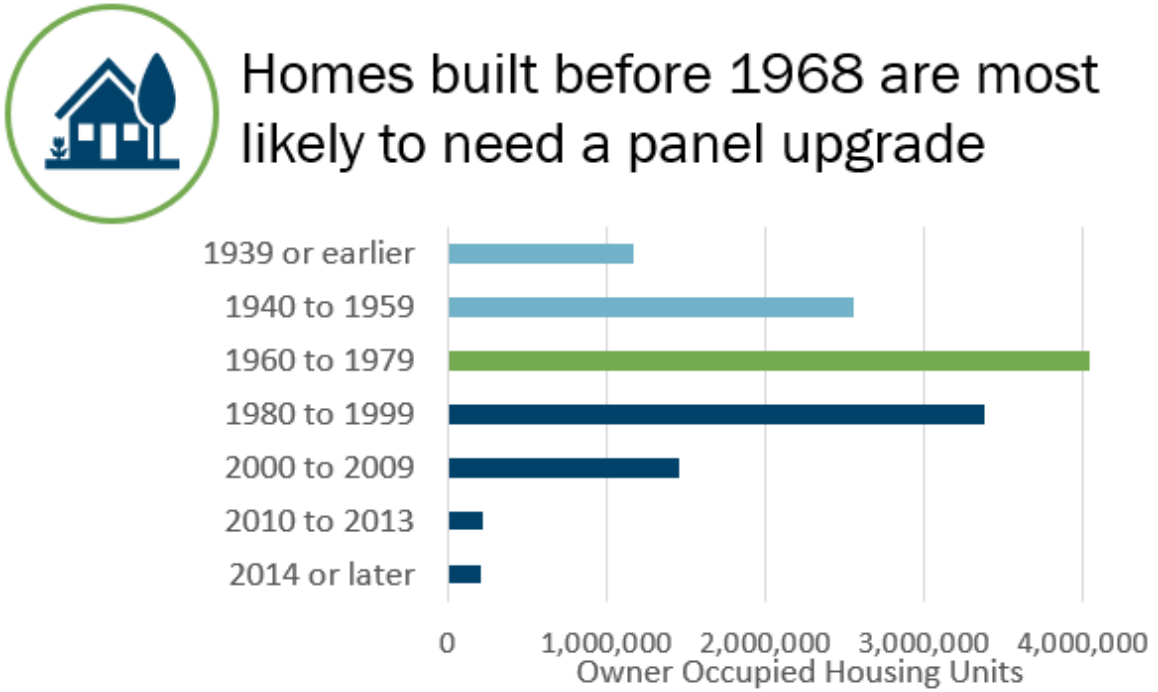
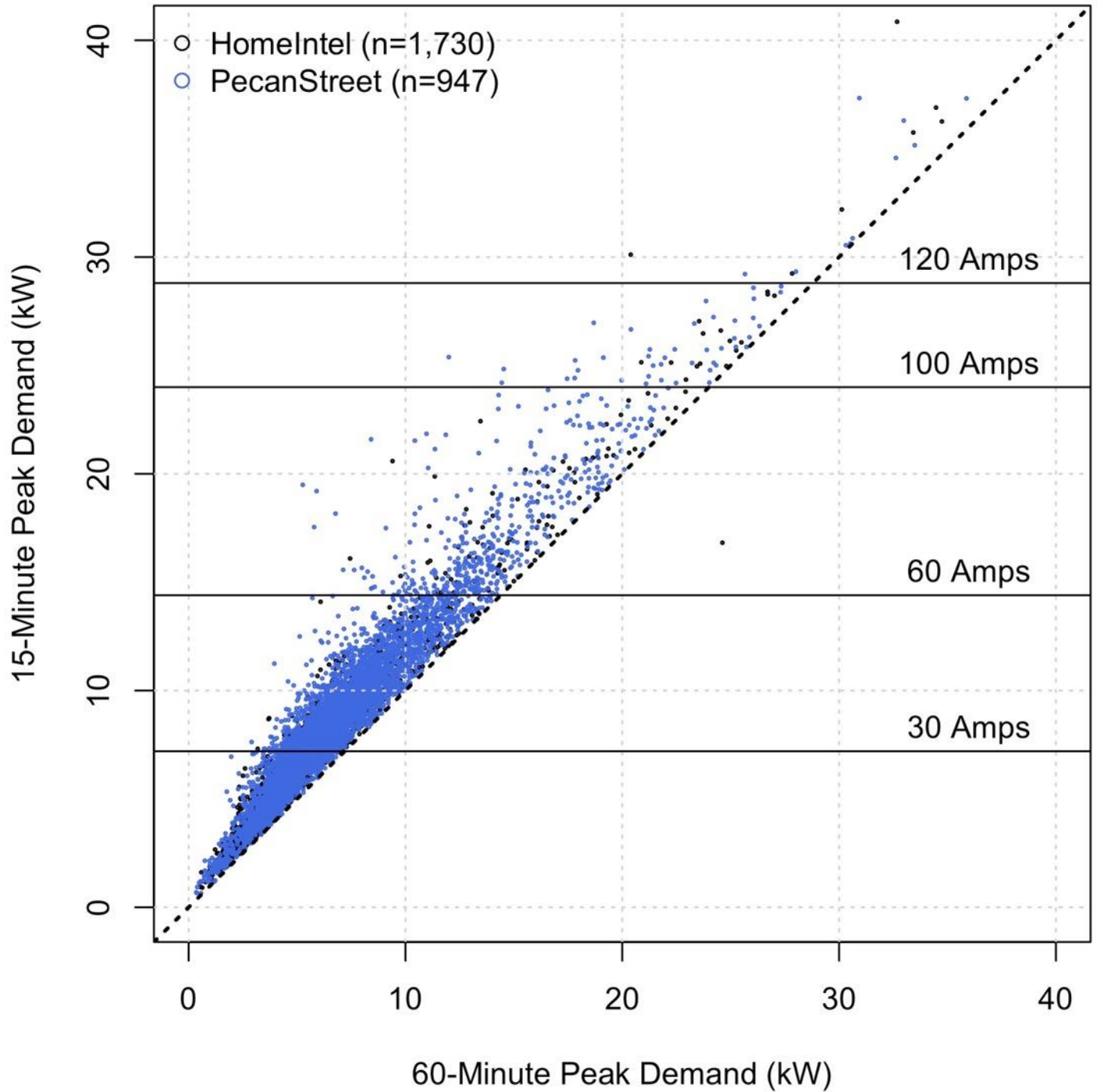
California Kitchens and 100-Amp Panels

- Single Family Homes older than about 1968 in California were not required to have 20-amp kitchen circuits, and are much more likely to not already have A/C (which ultimately required a 100-amp panel)

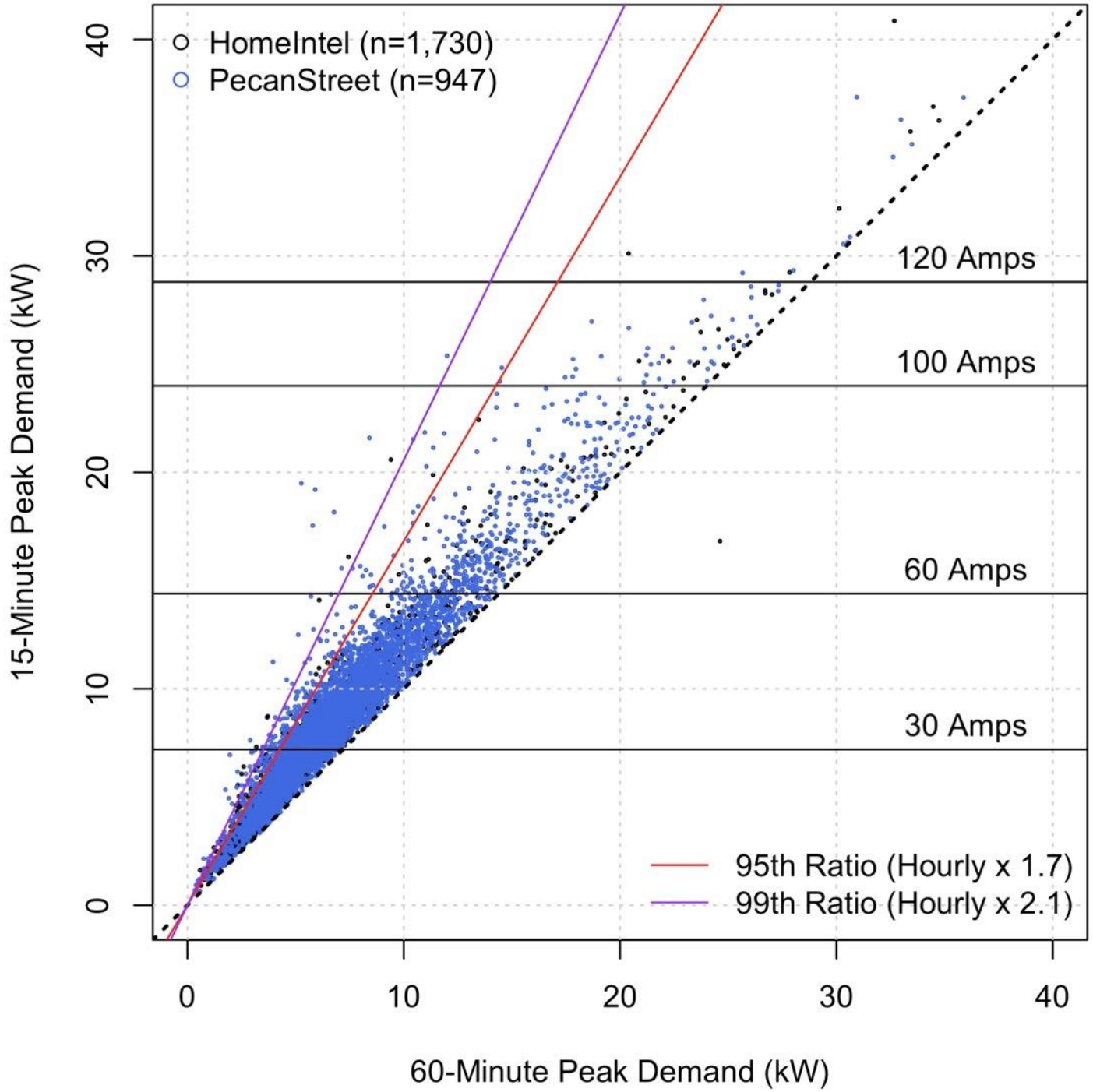


Can we predict 15 minute data from 60 minute smart meter data?



Can we predict 15 minute data from 60 minute smart meter data?

Basic Ratio Multipliers



Can we predict 15 minute data from 60 minute smart meter data?

Simple
Add-On