BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

All-Electric Homes on a 100A Panel

Iain Walker & Brennan Less

February 2023

FORUM ON DRY CLIMATE HOME PERFORMANCE

What’s the issue?

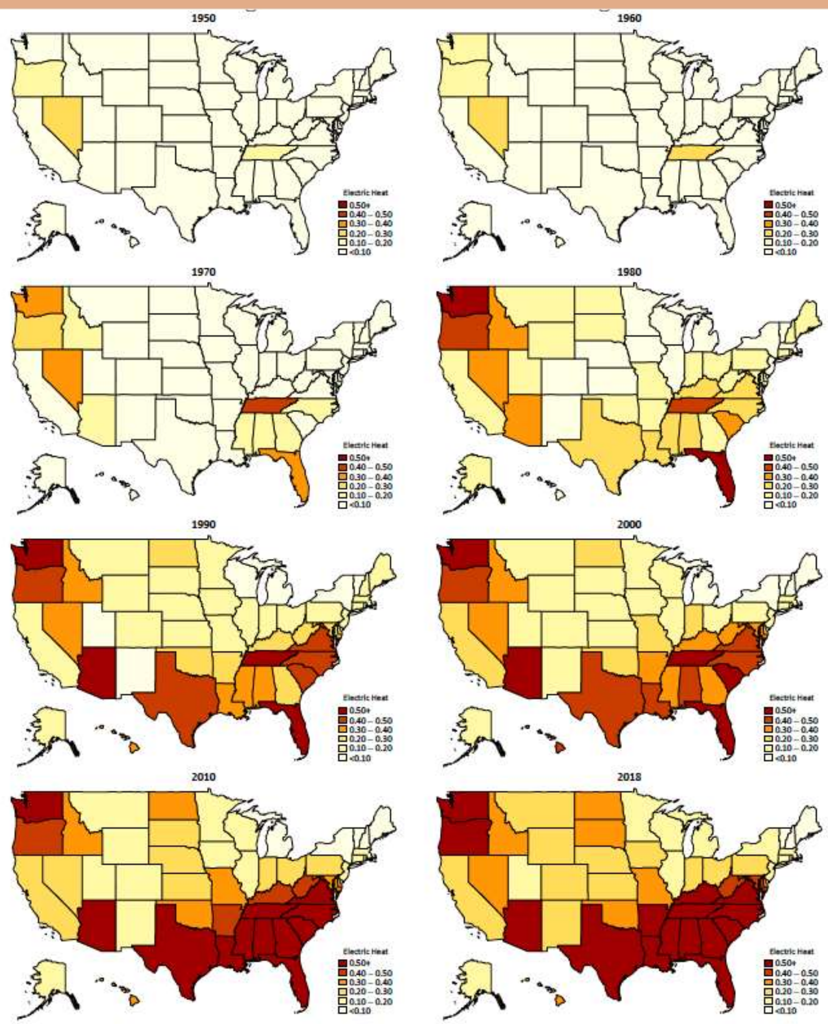
Decarbonization Retrofits

- New homes almost always have enough panel capacity – 200A typical
- Many existing homes have <200A
- Panel/wiring/service upgrades are costly (many thousands of dollars)
    - A big barrier to electrification/decarbonization

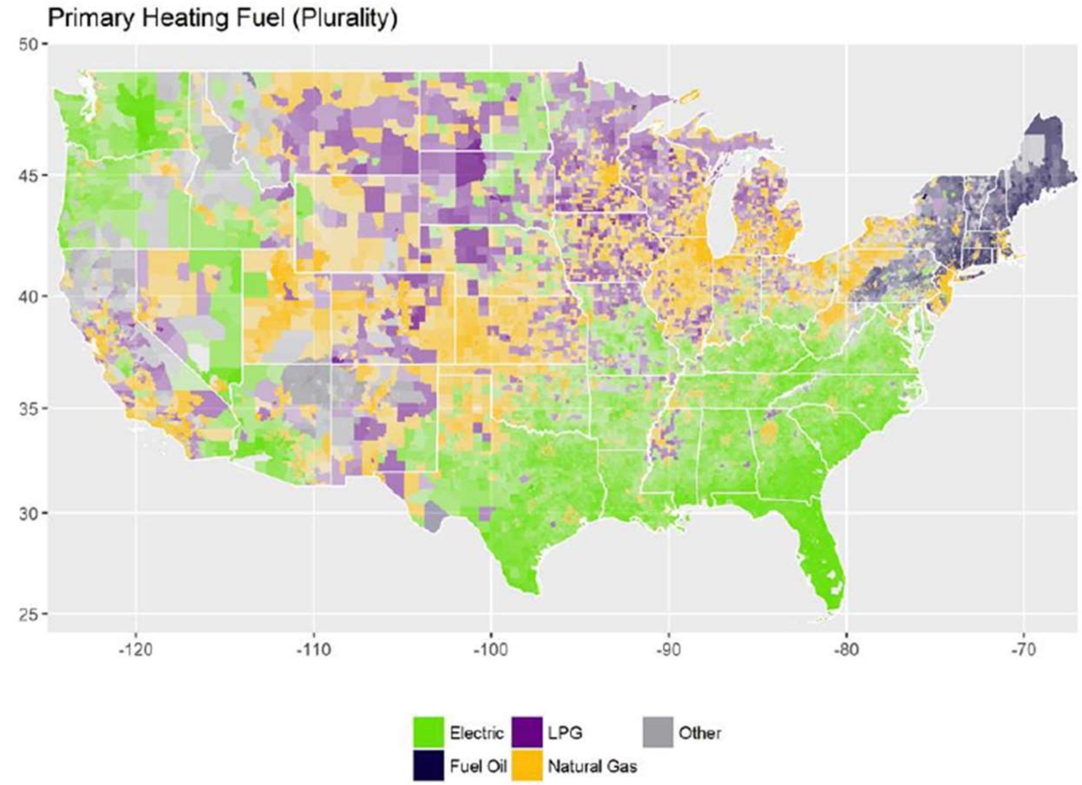
- *How do we minimize the cost to electrify existing homes???*
- Electrify for under 100A…and avoid that panel replacement

Electric Heating

Growth in Electric Heating



Distribution of Electric Heating



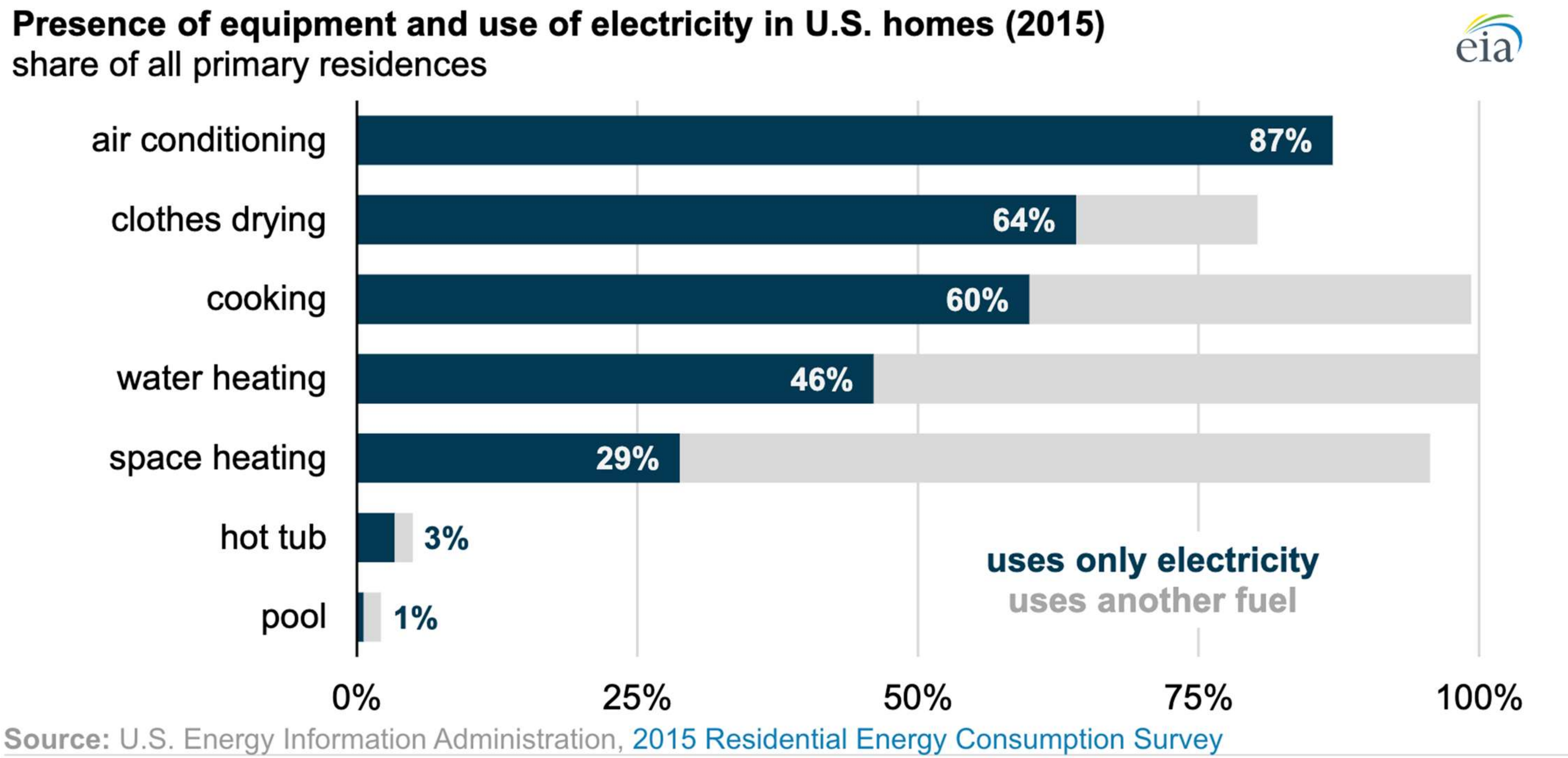
Data from the American Community Survey (2016).

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

Current Electric Appliances in the US

https://www.eia.gov/todayinenergy/detail.php?id=39293

#RESNET2022



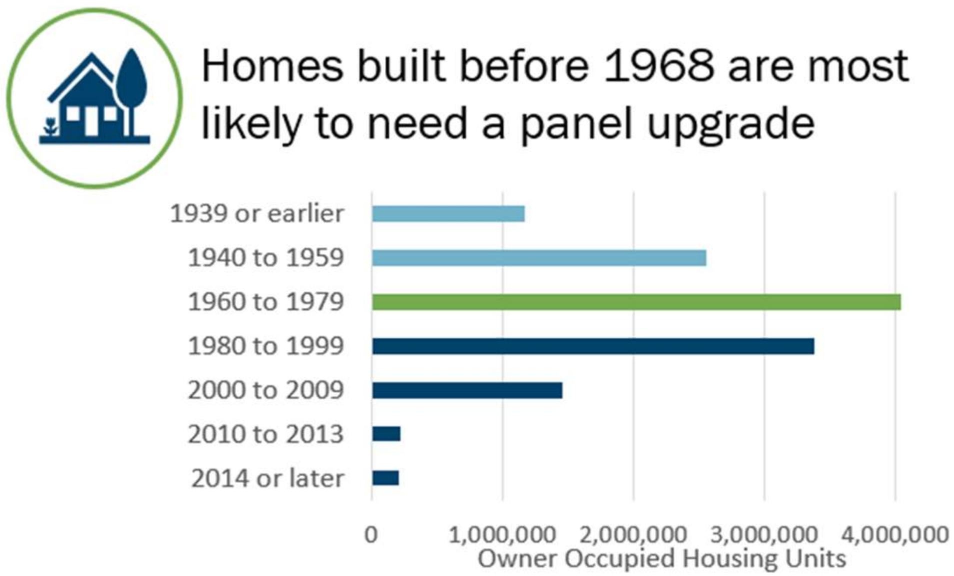
What’s Panels Are Actually Installed?

- **<u>Our Goal</u>**
  - Estimate panel amperage across the US housing stock using ResStock
  - Build machine learning models to predict amperage based on
    - Vintage, floor area, presence of major electrical end-uses, solar, EV, etc.

- What information do we have?
  - Code requirements by year
  - Citizen science data collection
  - Other assembled data sets

What's Actually Installed: California Kitchens and 100A 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)



What's Actually installed? Citizen Science

Background: It is difficult to estimate the extent to which panel capacities are a barrier to electrification because there is no national data on panel capacities

Approach: We recruit occupants of single-family homes with a national survey tool (Amazon Mechanical Turk).

Each recruit:

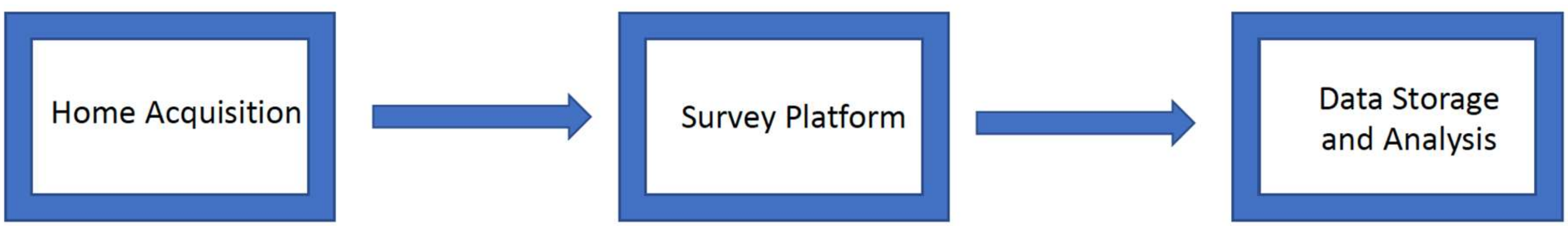
- fills out a short survey of appliances in homes, age of house, size, location, fuels used for heating, etc.
- photographs their electrical panel
- gets paid $2- $5

Results:

- 190 homes (increasing 10 - 15/week @ $5/home)
- histogram of panel capacities for homes by fuel, age, floor area, location
- available circuits for electrification

What's Actually installed?
Citizen Science

Approach to Acquiring Data on Panel and Home Characteristics



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

What's Actually installed?
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

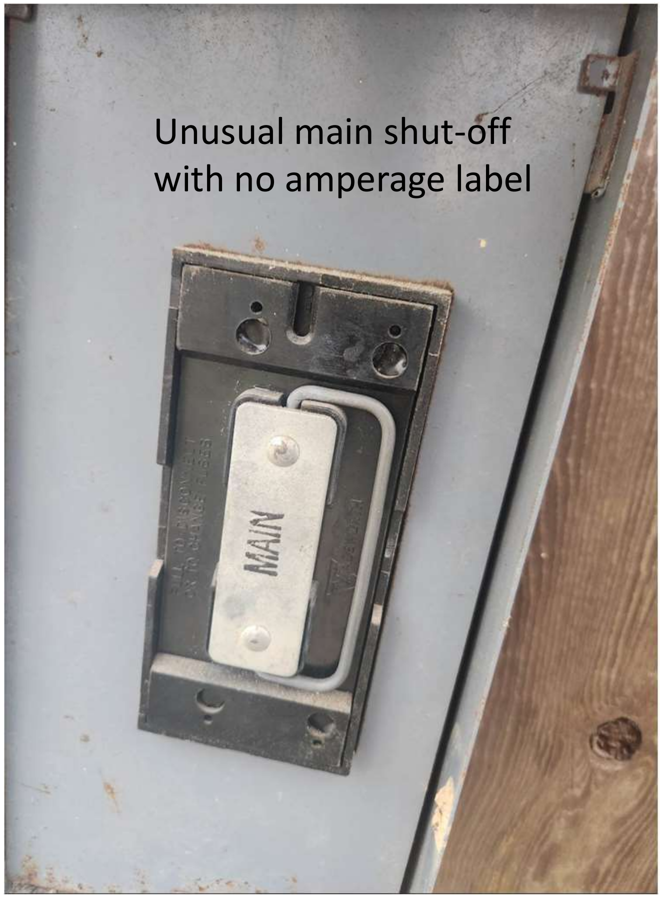
- Location (state, city, zip code)
- House year of construction
- Electric appliances in house
- Gas appliances in house
- 2 photos of electrical panel
- Input value of panel capacity (between 20-1000)

* 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)

What's Actually installed?
Citizen Science

What's Actually installed?
Citizen Science



What’s Actually installed?
Other Data Sources

Source	*Single-family*	*Multi-family*	*Project Count*	*Panel Amperage Data*	*Panel Space Available*	*Panel Upgrade Data*	*Peak Demand Data*	*Upgrade Cost Data*	*State*
TECH Clean CA	x	x	9609	x		x		x	CA
BayRen	x		6461	x	x				CA
NEEA RBSA	x	x	1279	x			~180 homes		OR, WA, ID, MT
Home Energy Analytics	x		497	x			x		CA
Eden Housing		x	80 MF Buildings (1000’s of units)	x	Visual review?				CA
EPRI Survey			>3,000	x	x				US
TOTAL			***17,846***						

What's Actually installed? Other Data Sources

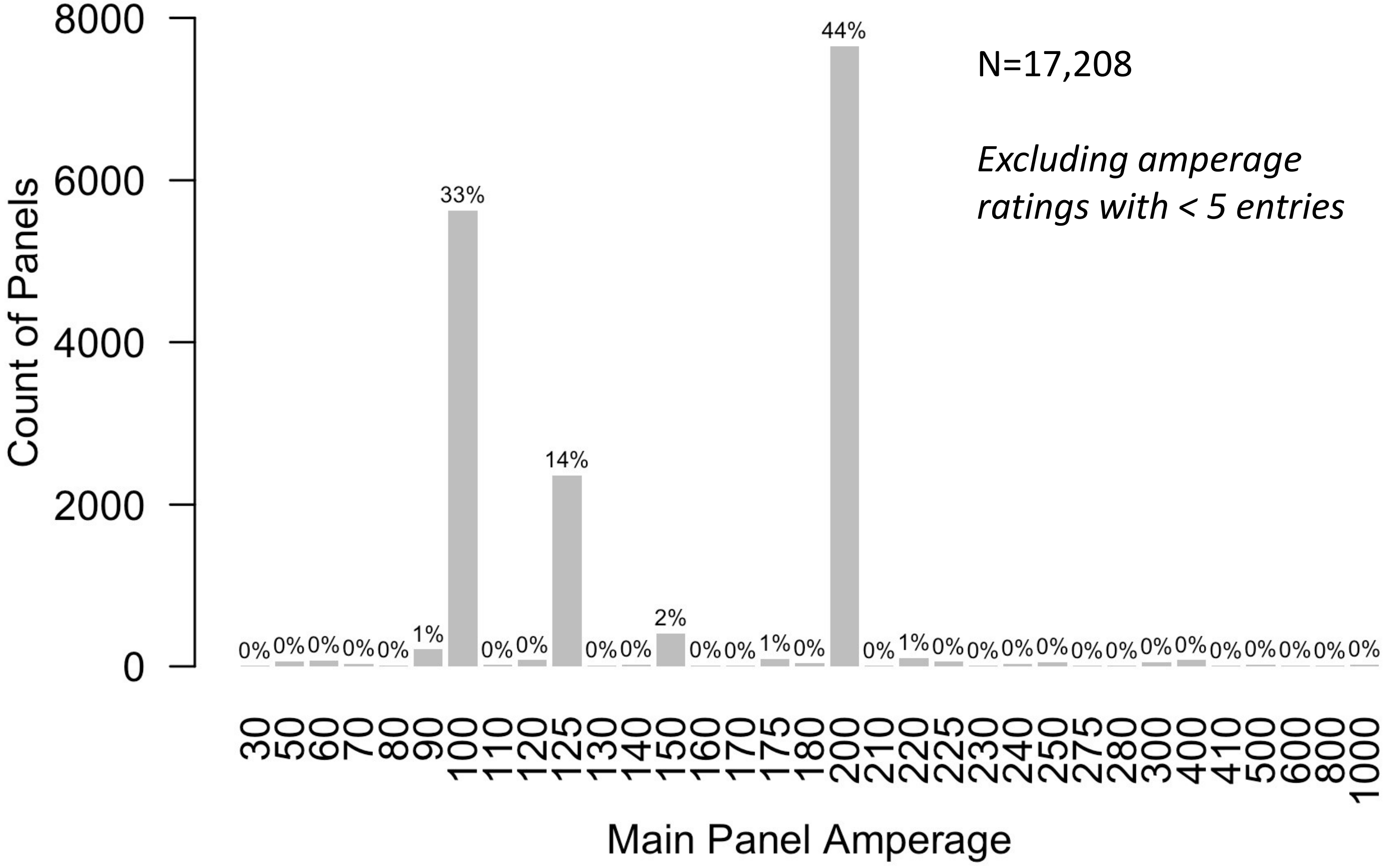
Source	***Single-family***	***Multi-family***	***Project Count***	***Panel Amperage Data***	***Panel Space Available***	***Panel Upgrade Data***	***Peak Demand Data***	***Upgrade Cost Data***	***State***
TECH Clean CA	x	x	9609	x		x		x	CA
BayRen	x		6461	x	x				CA
NEEA RBSA									OR, WA, ID, MT
Home Energy A									CA
Eden Housing									CA
EPRI Survey			>3,000	x	x				US
TOTAL			***17,846***						

Important Biases to Note:

- Most data sets represent homes engaging in EE programs (not random)
- Very strong bias to California housing stock
- Mostly single-family data

- Robust statistical models should allow us to over-come most of these limitations

What's Actually installed?
Other Data Sources



N=17,208

Excluding amperage ratings with < 5 entries

Vintage	Mean	Median	Mode
<1940	175	125	200
1940s	172	125	200
1950s	156	125	200
1960s	147	125	100
1970s	141	125	100
1980s	143	125	100
1990s	160	200	200
2000s	204	200	200
2010s	202	200	200
2020s	227	200	200
Unknown	163	200	200

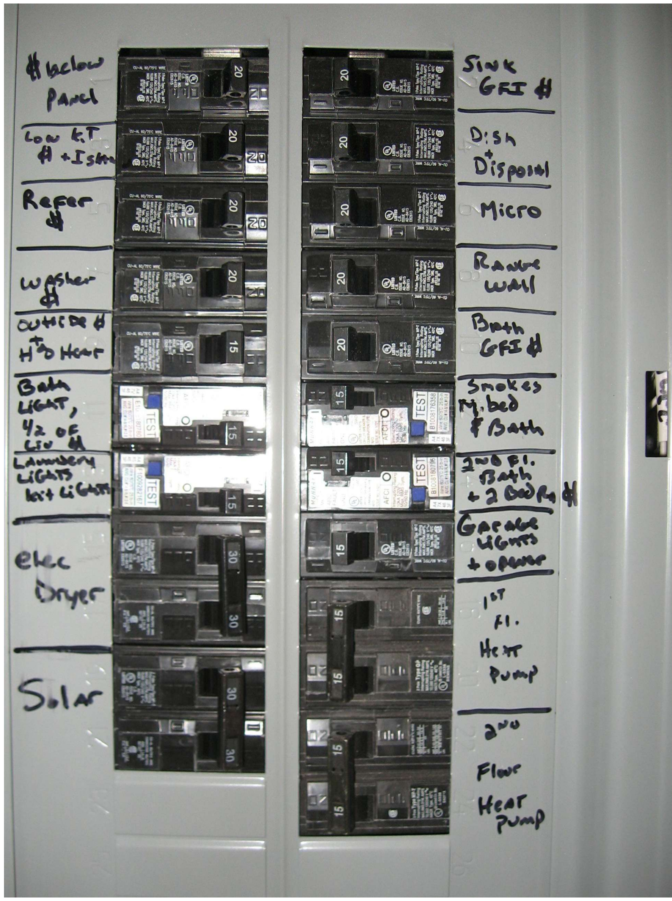
CoolingType	Mean	Median	Mode
Unknown	165	200	200
central_ac	163	175	200
evaporative_cooling	162	200	NA
heat_pump	179	200	200
no_cooling	157	125	100
room_ac	156	100	100

Has PV	Mean	Median	Mode
FALSE	163	125	200
TRUE	166	200	200

Why Not Just Upgrade to 200 Amps?

<u>California Overview:</u>

- 14 million homes in CA
- How many need panel upgrades?
  - **6 million** built before 1968 (when 100A became standard)
  - **8 million** based on gathered panel statistics
- What does it cost?
  - Household cost: **$3,000-$25,000** to homeowner + similar amount for utility
  - State-wide cost (very rough): **$25-$40 billion**
- Time delays
  - **3-6 months** project delay each upgrade
  - >1-year lead time on transformers
- Upstream impacts
  - Utility distribution system upgrades increase energy costs
  - Increasing system peak demand and worsening duck curve and carbon impacts
  - Utility might reject your interconnection



Objective 2. Understand the costs incurred by all parties when upgrading electrical service to residential sites

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
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

Objective 2. Understand the costs incurred by all parties when upgrading electrical service to residential sites

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

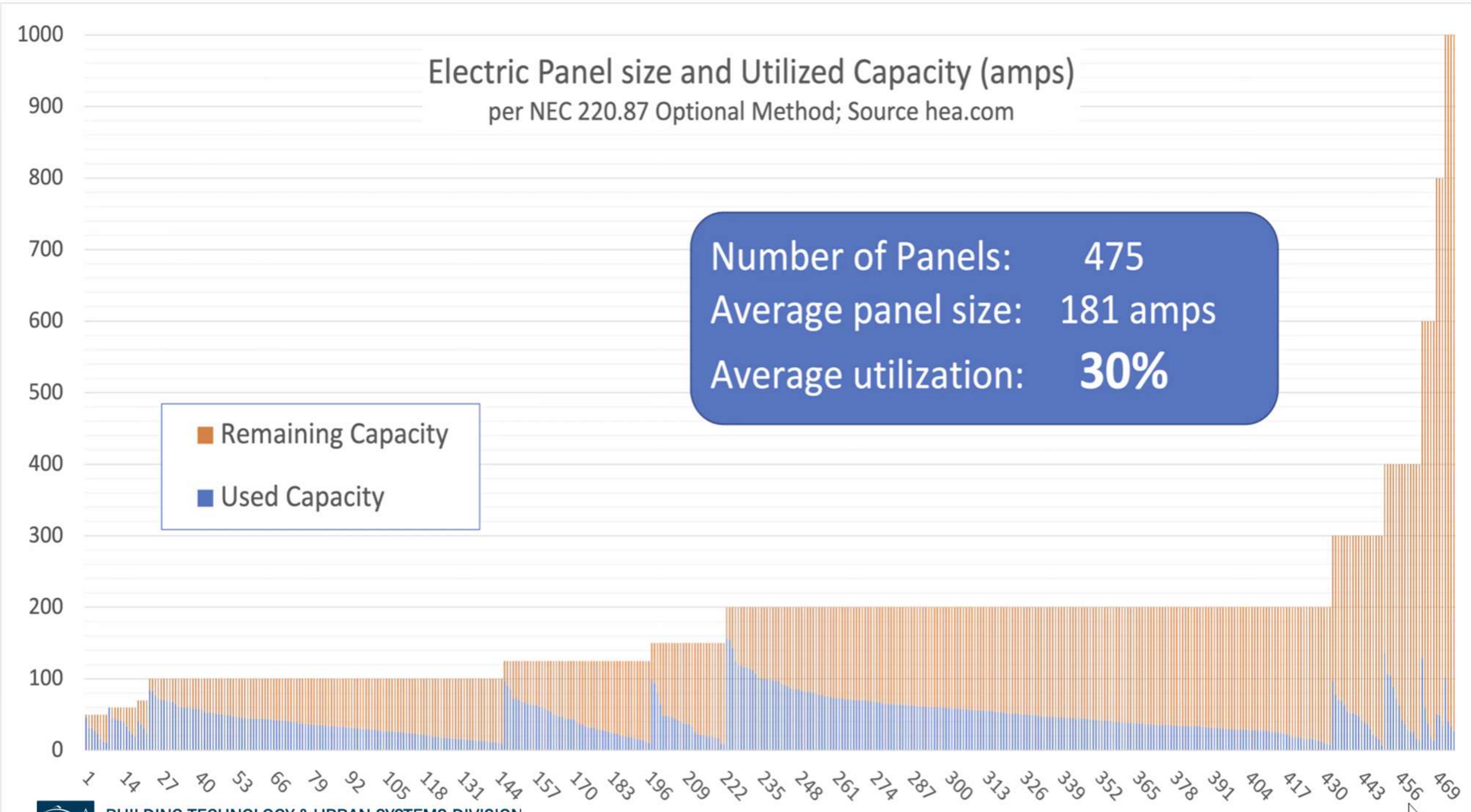
Cost Description	Average cost	Transaction
Transformer Upgrade	$6,000 - $8,000	Homeowner → Utility
Pole Replacement	$9,000 - $11,000	Homeowner → Utility
Total New or Upgraded Utility Equipment Service	$10,000 - $30,000	Utility → Contractor
Overhead line, service line only	$2,850 - $4,500 (Utility supplies 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

And avoiding redecorating…

Photo – Eric Morill

Available Capacity to Electrify

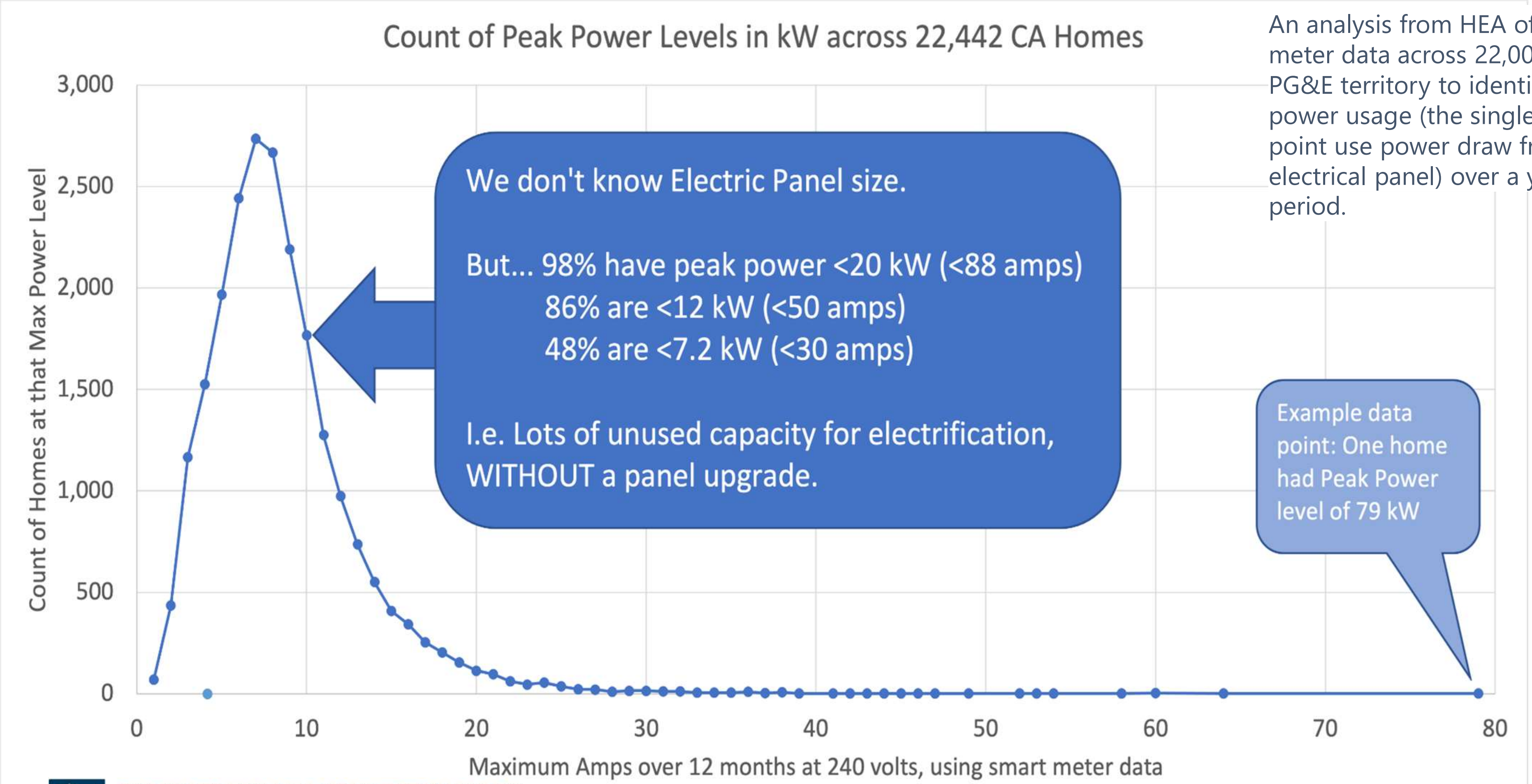


*Not a representative sample of all CA homes, and mix of all electric and electric + gas.

Source:
HEA, HomeIntel

BUILDING TECHNOLOGY & URBAN SYSTEMS DIVISION
Energy Technologies Area

Available Capacity to Electrify



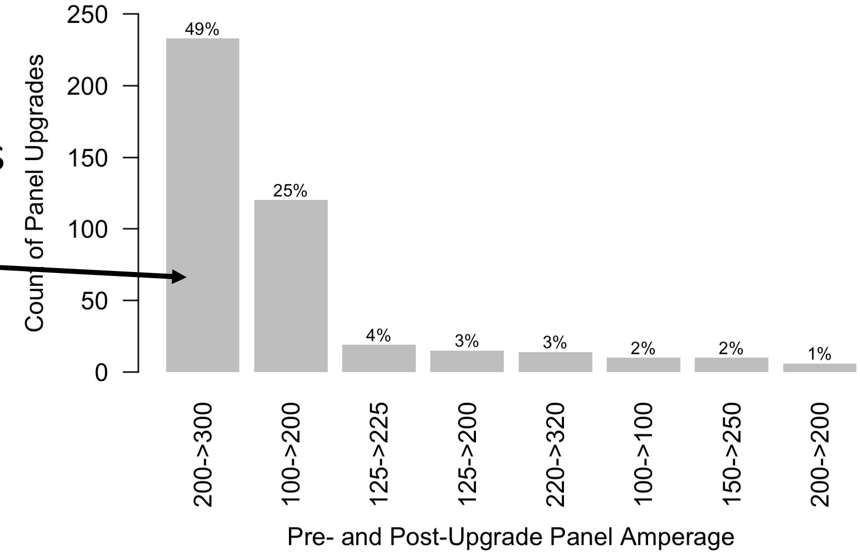
An analysis from HEA of smart meter data across 22,000 homes in PG&E territory to identify peak power usage (the single greatest point use power draw from their electrical panel) over a year-long period.

Source: HEA, HomeIntel

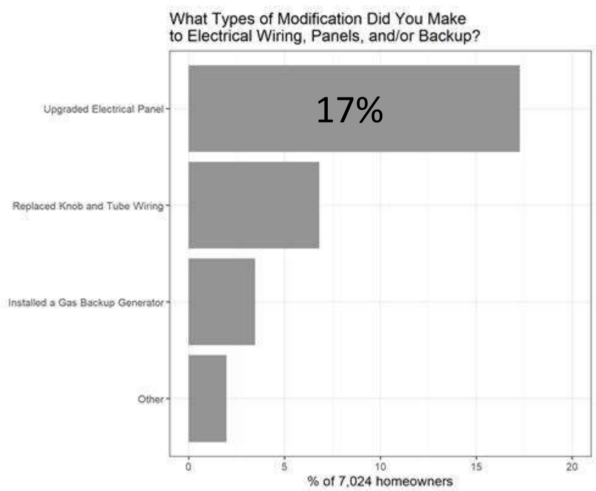
How Frequent Are Panel Upgrades?

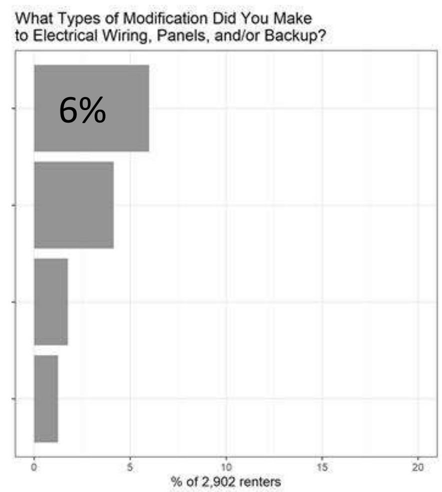
TECH Clean California

- 480 panel upgrades out of 10,446 heat pump upgrades (**4.6%**)
  - **Most panel upgrades were from 200A to 300A (n=239)**
  - Smaller set of upgrades were from 100A to 200A (n=135)



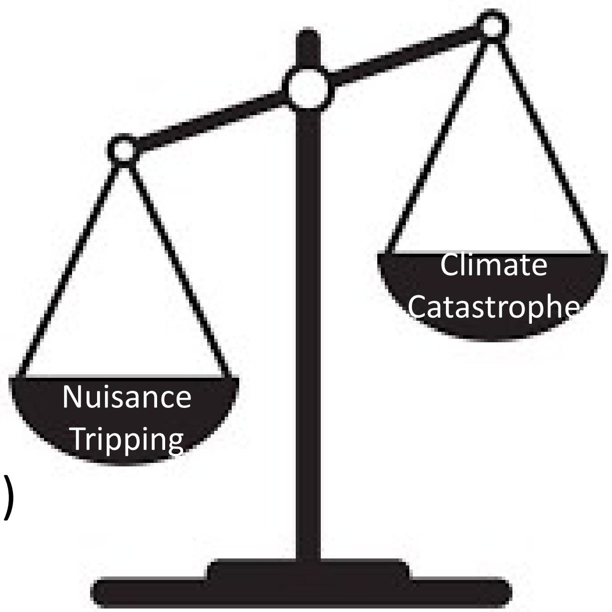
PNNL home occupant survey





What Drives Panel Upgrades?

1. Over-simplified approaches by electricians
   - Don’t use paths in National Electric Code (NEC)
   - Not enough space in the panel
   - Not enough amperage
   - Habit…
2. NEC not developed for electrification retrofits
   - Likely too conservative
   - No balance between nuisance tripping and climate calamity
   - Inconsistent national adoption keeps the market behind the code
3. Local code authorities are not prepared
   - Some will not allow circuit sharing/smart panels
4. Current driver is adding PV and EV (and additions/remodels?)
   - 80% rule for back-fed PV interconnections
   - 125% continuous load treatment for EVs
   - Future drivers: cooking, heat pumps, clothes drying, pools



Sometimes an update is needed

Old, unsafe or damaged panels

Fuse Boxes

Zinsco/GTE Sylvania and Federal Pacific panels have dangerous design flaws and should be removed

Do we have enough physical space in panels?

- BayRen Home Electrification Checklist
  - 100A: 31% have free space (70% need “space” solutions to add loads)
  - 200A: 48% have free space

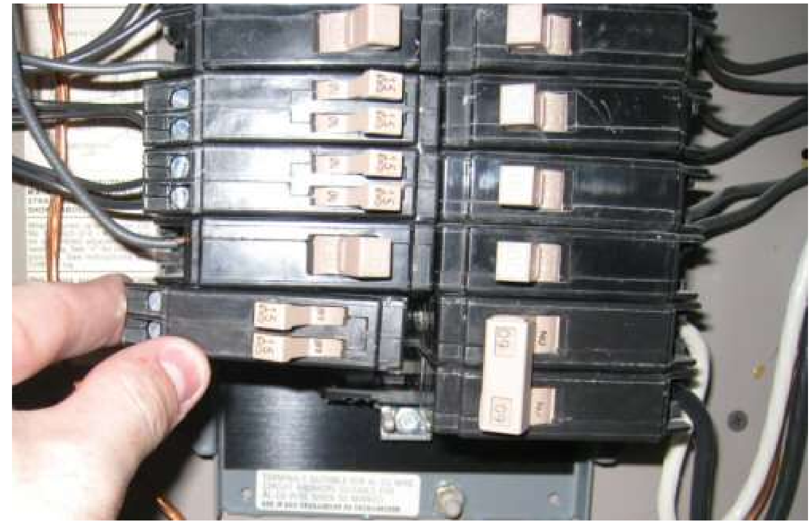
- Visually evaluating this in Citizen Science study as well:

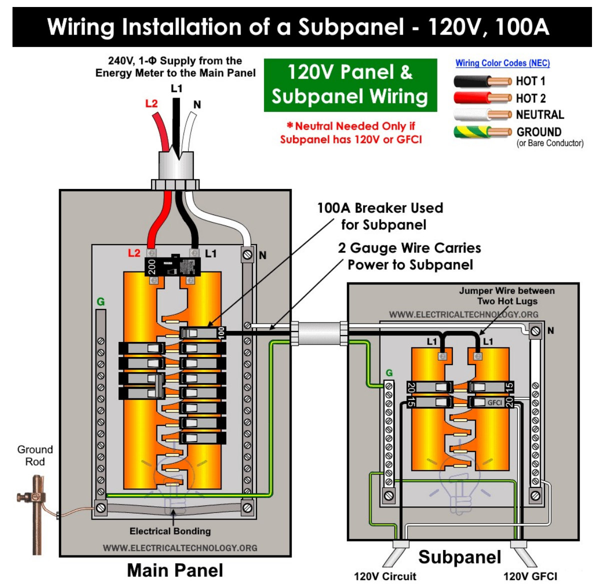
NO SPACE

LOTS OF SPACE

Solving the ”No Space” Problem

- Tandem breakers (panel and code limits)
- Sub-panel
- Circuit sharing/splitting





Utilizing the NEC
- 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.

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

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

100 Amp Panel

Device Volts	Device Amps	Circuit	Breaker	Breaker	Circuit	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

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

Improving Power Efficiency

Smart Circuit Splitters and Sharing

EV-PowerShare[xliii]
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)

Smart Circuit Pauser

Smart Circuit Breakers

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

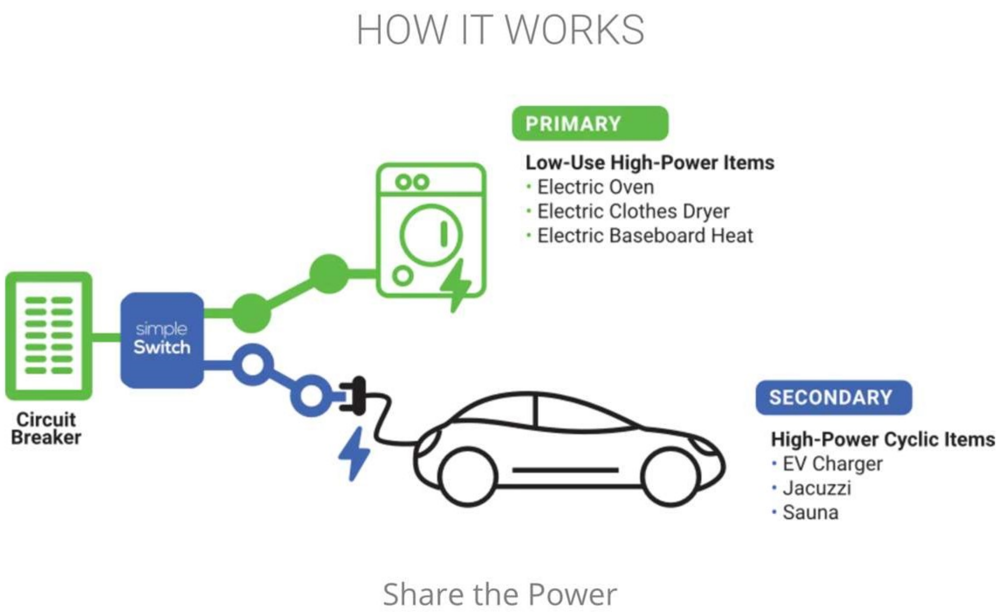
Meter Collars

homes.lbl.gov

Circuit Splitters and Circuit Pauser Diagrams

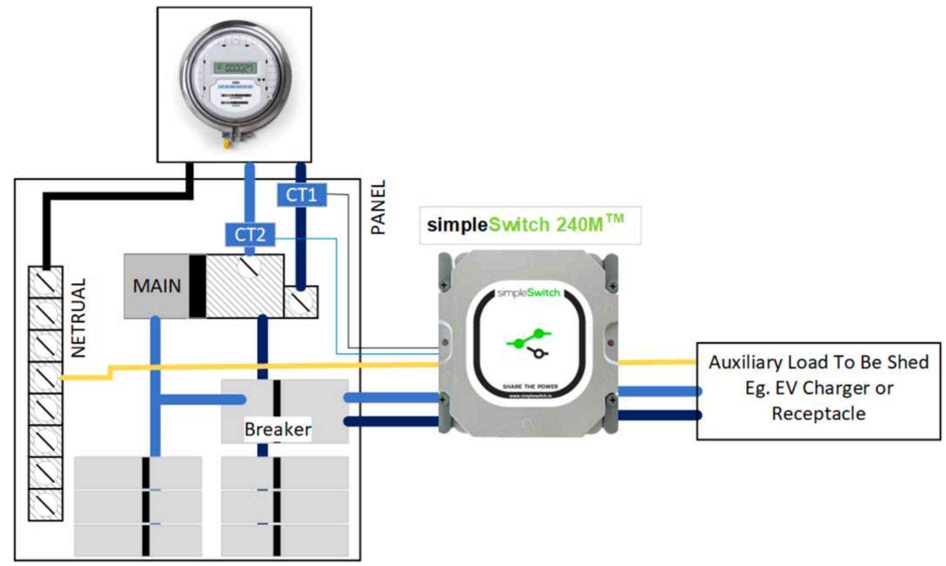
Circuit Splitters

- Connect two loads to same circuit
- Select priority load
- Automated switching
- Count only larger load against panel capacity



Circuit Pausers

- Controls one load based on demand metered with CTs
- Turns off at 80% of setpoint limit
- Do not count load against panel capacity



Load Sharing and Circuit Splitting

Smart circuit splitters allow two devices to share a single circuit, which can help avoid an electrical panel upgrade

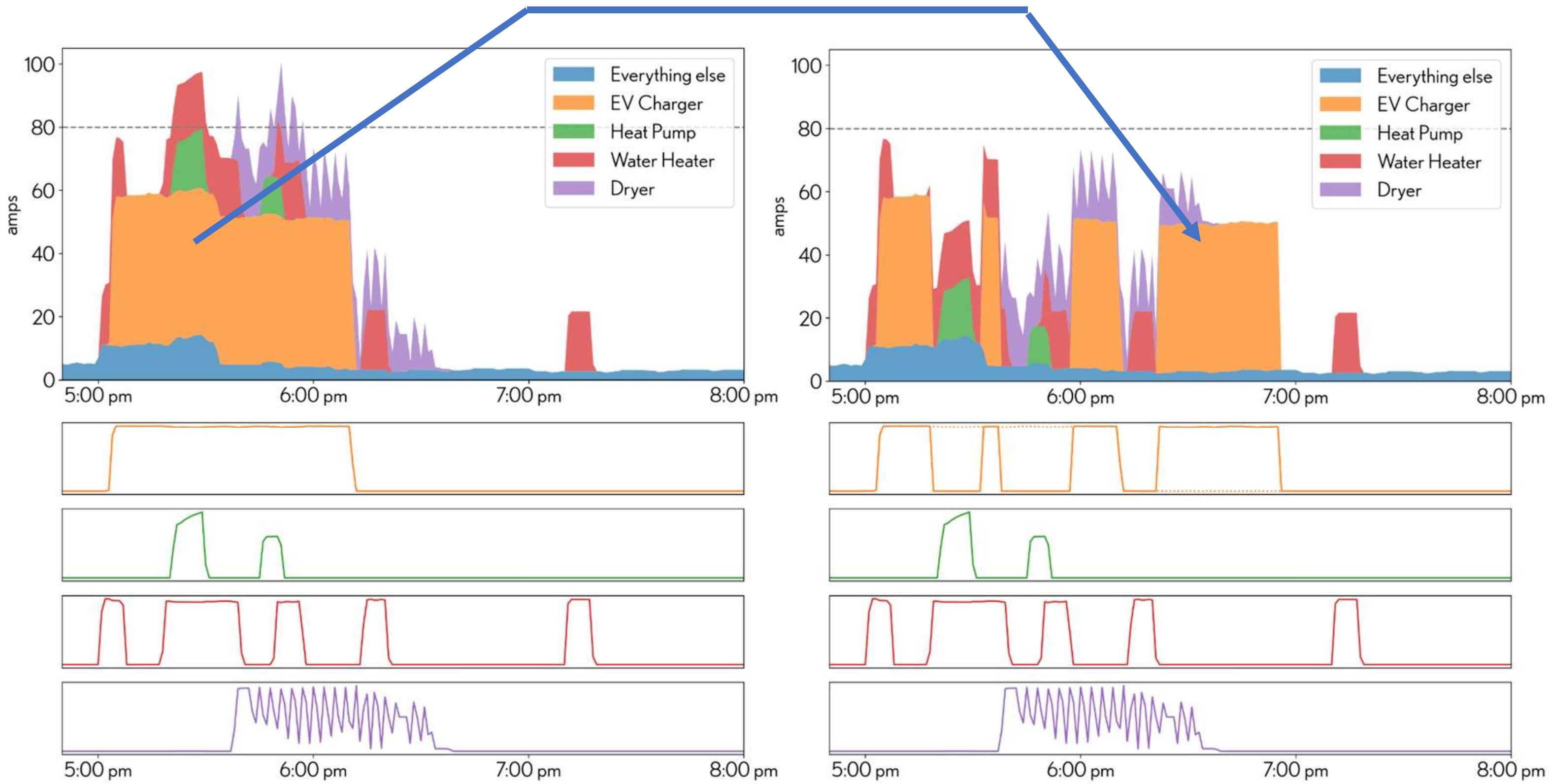
Most common sharing between an EV charger and an electric clothes dryer.

	Neo Charge[116] Smart Splitter 	**BSA Electronics**[117] Dryer Buddy 	**SimpleSwitch**[118] 240V Circuit Switch 	**Splitvolt**[119] Splitter Switch 	**Thermolec**[120] DCC 	**Evduty**[121] Smart Current Sensor 
Cost ($)	$500 (Appliance) $550 (Dual Car)	$200 – 365 (several outlet versions)	$550 (240V) $650 (EV) $550 (120V)	$319	$1,050 (DCC-9), $945 (DCC-10)	$500
Switch On/Off Between Two Devices	Yes	Yes	Yes	Yes	NA	NA
Continuous Power to Two Devices	Yes	Yes	No	No	NA	Yes, *shares power between appliance circuit and EV circuit*
Monitors Whole House Loads	No	No	No	No	Yes, *if total panel exceeds 80% rated load, turns off EV charging. Reconnects automatically*	Yes, *monitors a unit/home's current draw, left over current will be used to charge EV*

Load Sharing and Circuit Splitting

Classic peak case: come home from work and plug in car, turn up heat, start laundry

Smart device shifts EV charging later avoiding big peak



Sam Calisch, Rewiring America, Data from SPAN.io

Evaluation of Splitters and Pausers

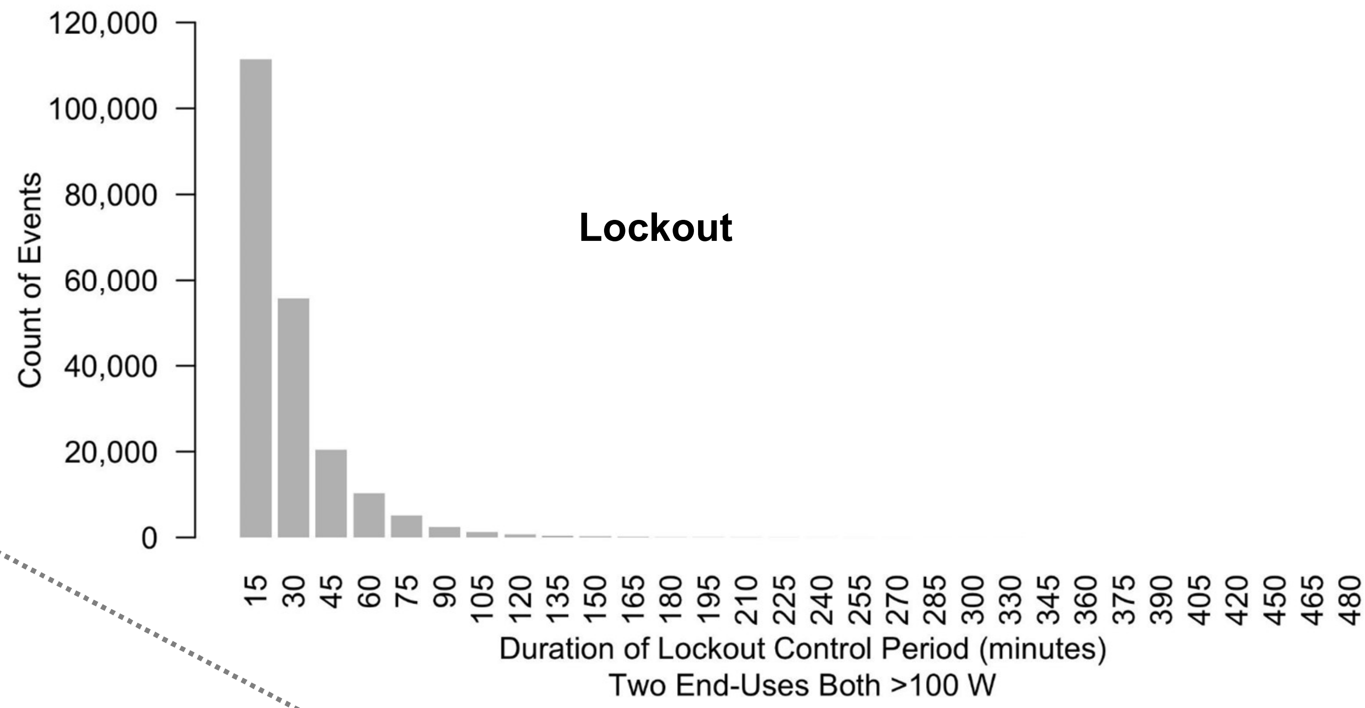
- Use end-use sub-metering data from occupied homes to estimate load controls potential/behavior (NEEA EULR end-use data). These homes DO NOT have controls, simply evaluating potential.

- Two types of control:

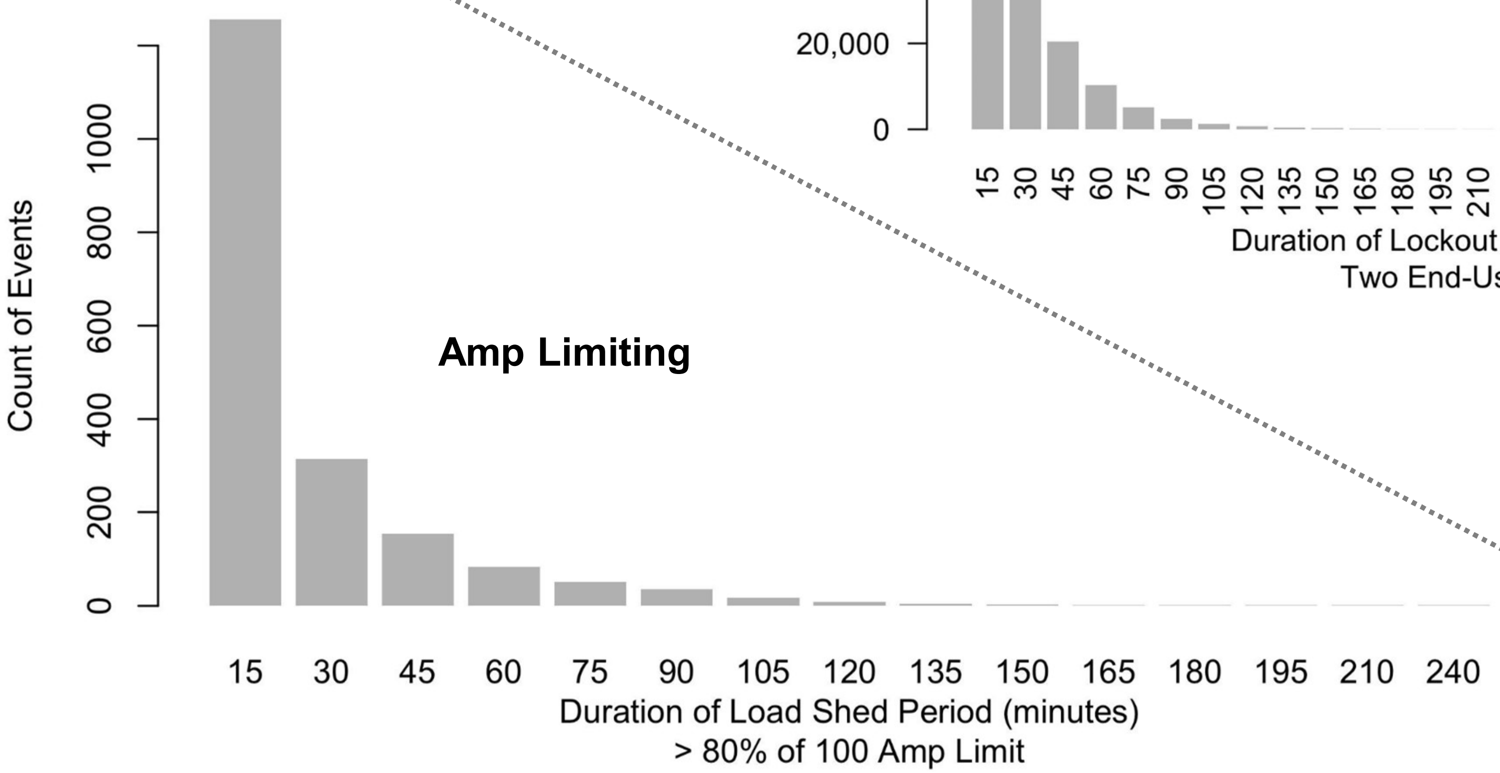
  - **Lockout controls.** Where two end-uses are connected to the same circuit. Control activates when both loads register >100w during the same time-step. Test all pairwise combinations of these appliances:
    - Dryer
    - DHW
    - EV
    - Hot tub
    - Cooking

  - **Amp limiting controls.** Where the mains are monitored and need to be limited to < 80% of a 100A limit. Controls activates when the mains are > 80% of 100A.

Duration



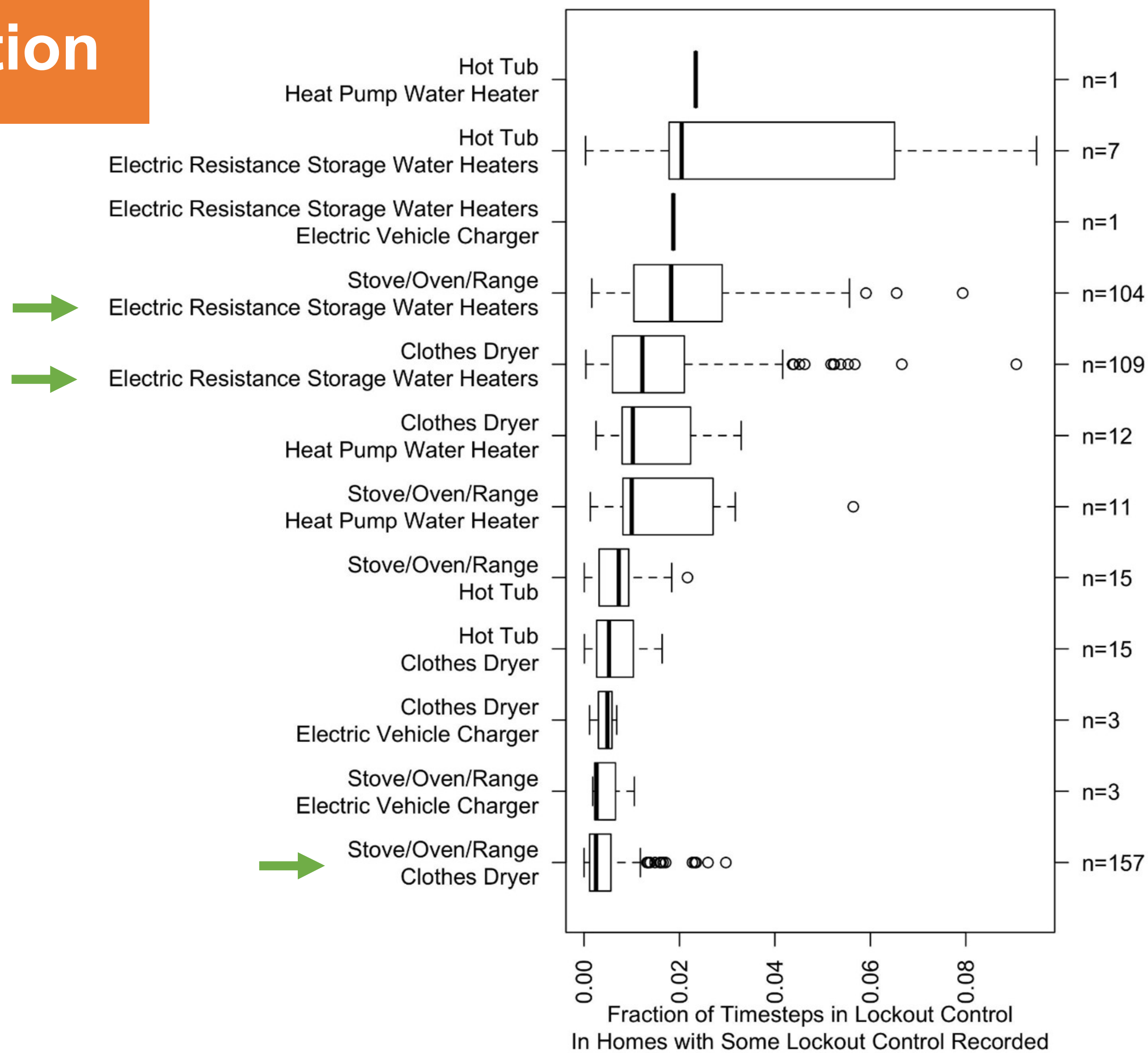
Lockout
120,000
100,000
80,000
60,000
40,000
20,000
0
Count of Events
15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 330 345 360 375 390 405 420 450 465 480
Duration of Lockout Control Period (minutes)
Two End-Uses Both >100 W



Amp Limiting
Count of Events
0
200
400
600
800
1000
15 30 45 60 75 90 105 120 135 150 165 180 195 210 240
Duration of Load Shed Period (minutes)
> 80% of 100 Amp Limit

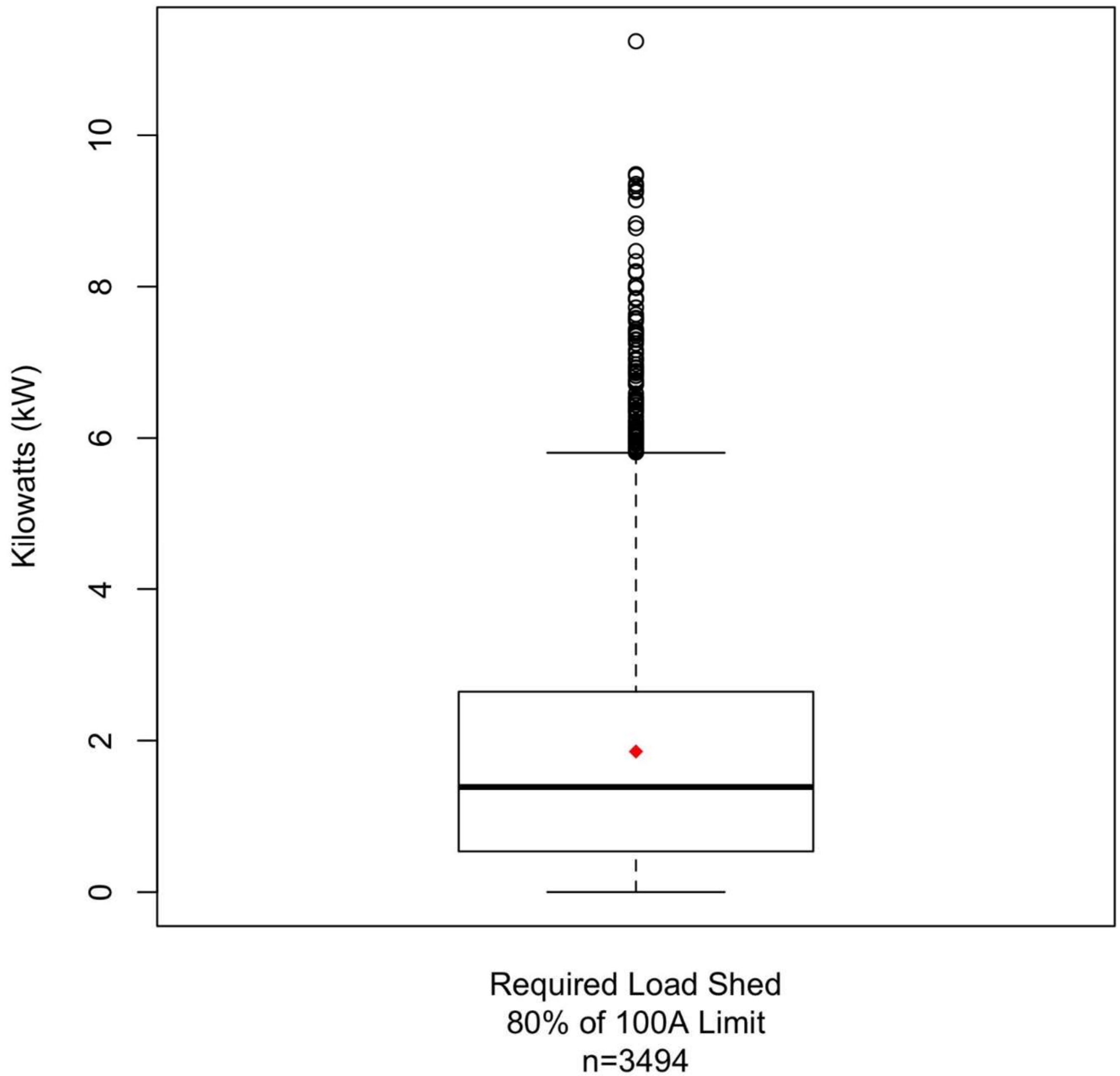
Lockout Controls Operation

- Typically 1-2% of the year (at most 10%)
- Goal: common end-uses with high demand and infrequent coincidence?
    - Stove + Clothes Dryer



Amp Limiting
Required Load Shed

- Amp limiting periods occurred in only ~20% of homes
- Typically 1-2 kW required load shed

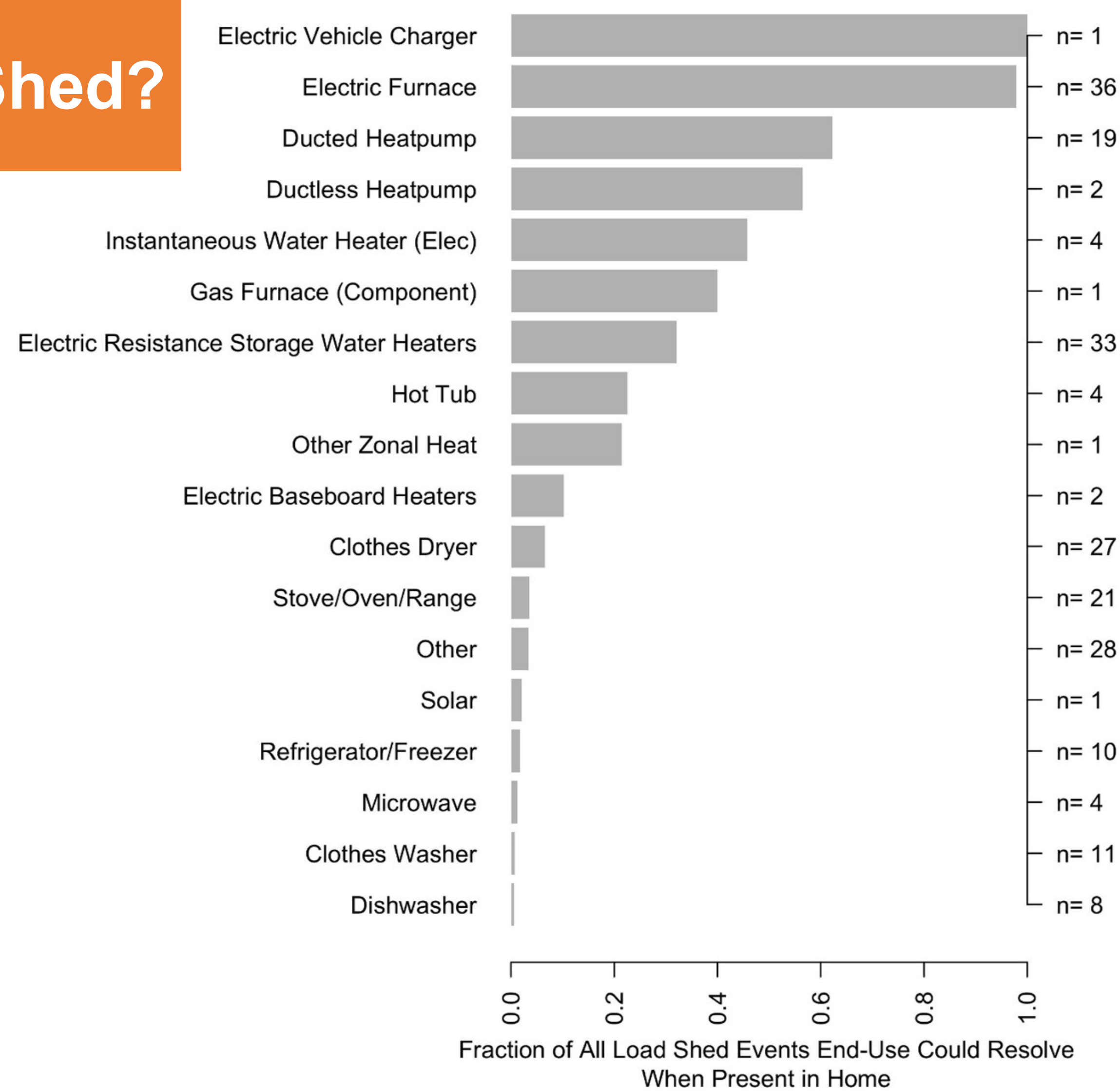


What End-Uses Can Provide the Required Load Shed?

An end-Use is “capable” if it is:

1. In the home
2. On during the load shed event/timestep
3. At a wattage capable of satisfying the required load shed

Most end-uses resolve <1/2 of load shed events



Load Sharing and circuit splitting challenges

Codes and Regulations

- Does the NEC correctly account for these devices – or include them at all?
- Does you local authority allow their use?
- NEC 220.60 “Noncoincident Loads” appears in 2023!
- NEC 220.70 “Energy Management Systems” appears in 2023!

Home Infrastructure

- If you don’t have an existing electric dryer circuit to share with an EV
- Location of load doesn’t easily integrate with EV pausing

Usability

- Users may not like pausing functionality for important loads
- Most loads do not “pause” easily. Think clothes dryer vs. EV.
- Need more advanced appliances, communications and solutions

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**

Bigger Challenges…

- Solar PV
- Electric Vehicle Charging

The Challenge of Integrating Solar PV

- NEC 80% Rule to protect the busbar

- PV Amps = Main Breaker rating - Busbar Rating x 80%
  - 100A – (100A * 80%) = 20 Amp/4,800w solar
  - 200A – (200A * 80%) = 40 Amp/9,600w solar
  - 300A – (300A * 80%) = 60 Amp/14,400w solar

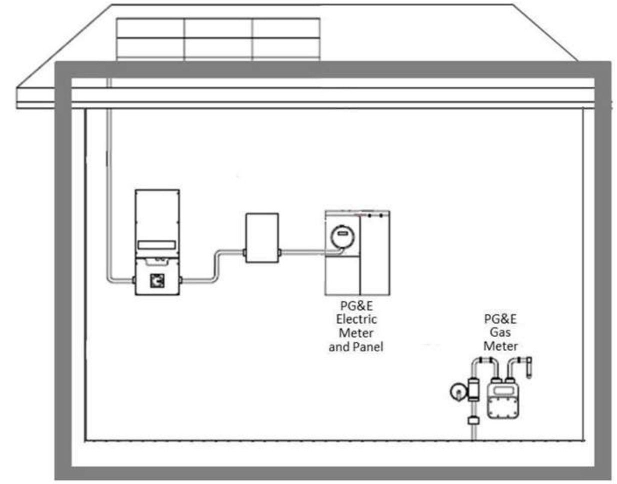
- Solutions:
  1. De-rate the main breaker (e.g., from 200 to 180A allows 20A more of solar), but need to ensure the load from the grid is still served.
  2. Install solar ready main panel that avoids back-feeding the solar circuit through the busbar. Akin to a line-side connection, but built into the panel itself.
  3. Line-side connection that does not use the busbar (connect solar upstream of the service disconnect. Each utility regulates these interconnections differently.
  4. Feed the existing main breaker into a sub-panel with a higher busbar ampere rating. I don't fully understand this one...

Meter Collar Solutions bypass internal busbar current limit

EXISTING PRODUCT - SOLAR

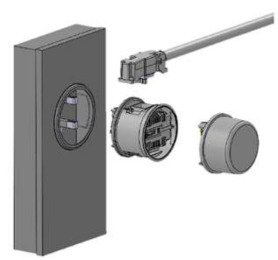
- Solar Adapter
  - UL Listed (414 - Meter Sockets)
  - 5 mins to install, 30 mins to interconnect
  - 200A continuous rating, utility power
  - 80A continuous rating, PV input (15kW)
  - Integrated PV breaker
  - Optional smart module – RGM and cellular comms
  - Approved in 20 states
  - 15,000 units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

PG&E Green Meter Adapter

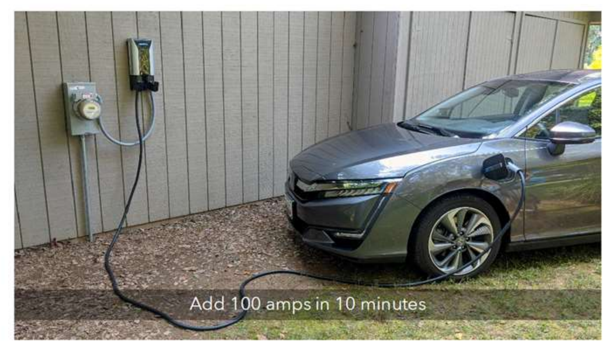


WE TURNED THE METER SOCKET INTO AN ELECTRICAL OUTLET

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



Add 100 amps in 10 minutes

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 A
  - 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

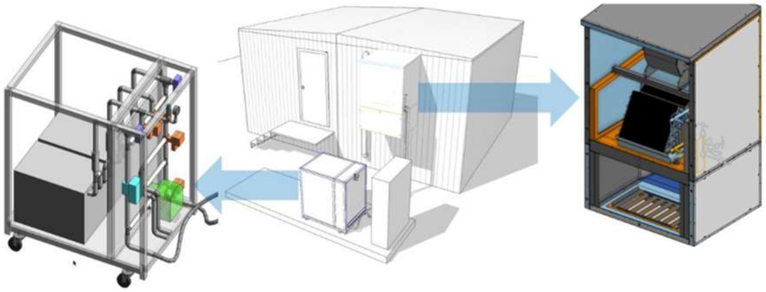
The Equitable and Affordable Solutions to Electrification (EAS-E) Home Electrification Prize provides up to $2.4 million in prizes for innovative solutions that advance electrification retrofits of residential homes across all building types and geographies.

Leave a Message

New Ideas?

- Battery-integrated appliances: Battery-integrated stove never draws more than 1500W, compared to several kW for traditional stove

- 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)

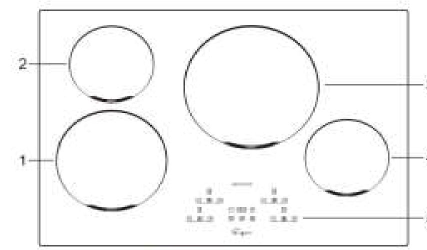
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Residential Cold-Climate Heat Pump Technology Challenge

New Ideas?

20A Induction Range Design Test
CalFlexHub Project

- Develop a fully functional 20A range
  - Normally requires 40A circuit
  - Use power sharing

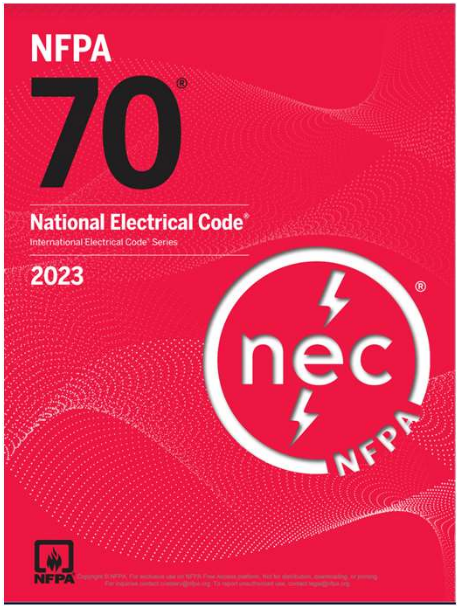


EMPV-30EC02

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

New Ideas – updating NEC for electrification retrofits

- Updating NEC to better accommodate home electrification
  - What are actual coincident loads?
  - How close are most homes to panel capacity and ability to add loads?
  - Allow load reductions/load control
    - Power Efficient Appliances
    - Circuit Sharing
    - Energy storage



NEC Options

NEC 220.87

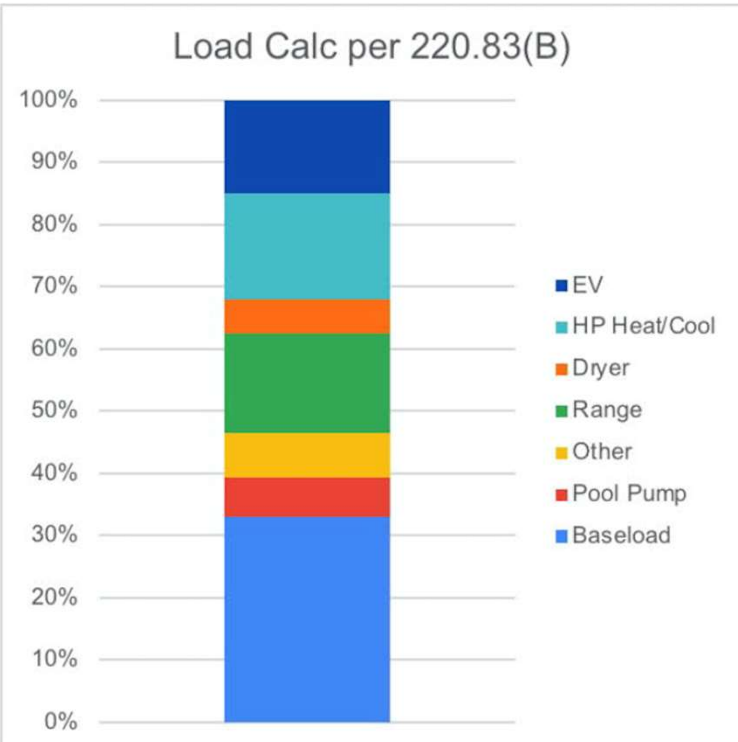
- Existing loads based on metering data (15 minute)
- Total load = (Metered Load) x 1.25 + New Load

NEC 220.83

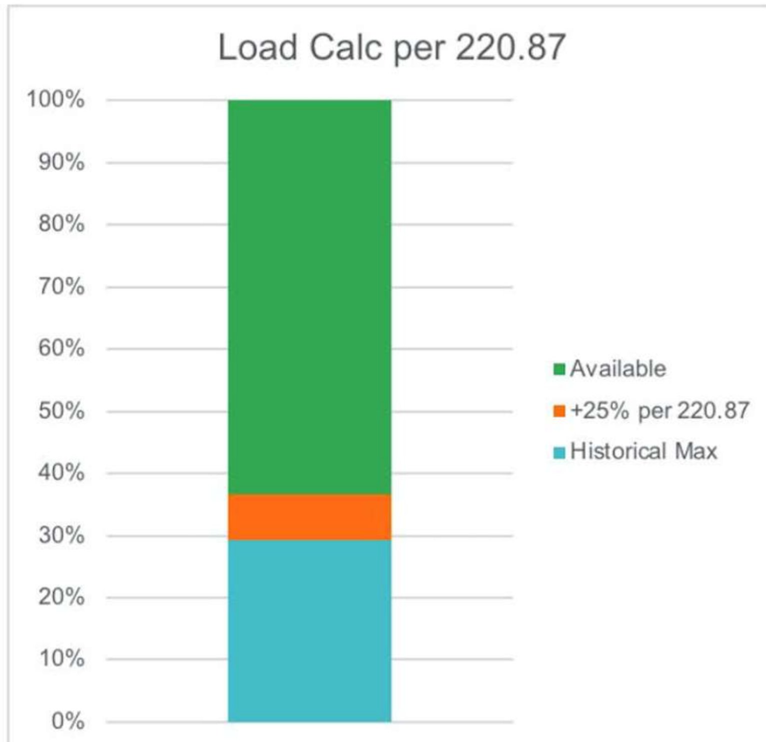
- Existing loads as a bottom-up summation of connected loads with different treatment when adding HVAC
- No New HVAC: 8,000 watts + 40% of remaining connected loads (including heating and cooling)
- New HVAC: 8,000 watts + 40% of remaining connected loads + max(heating, cooling)

Comparison of load calculation options

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



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



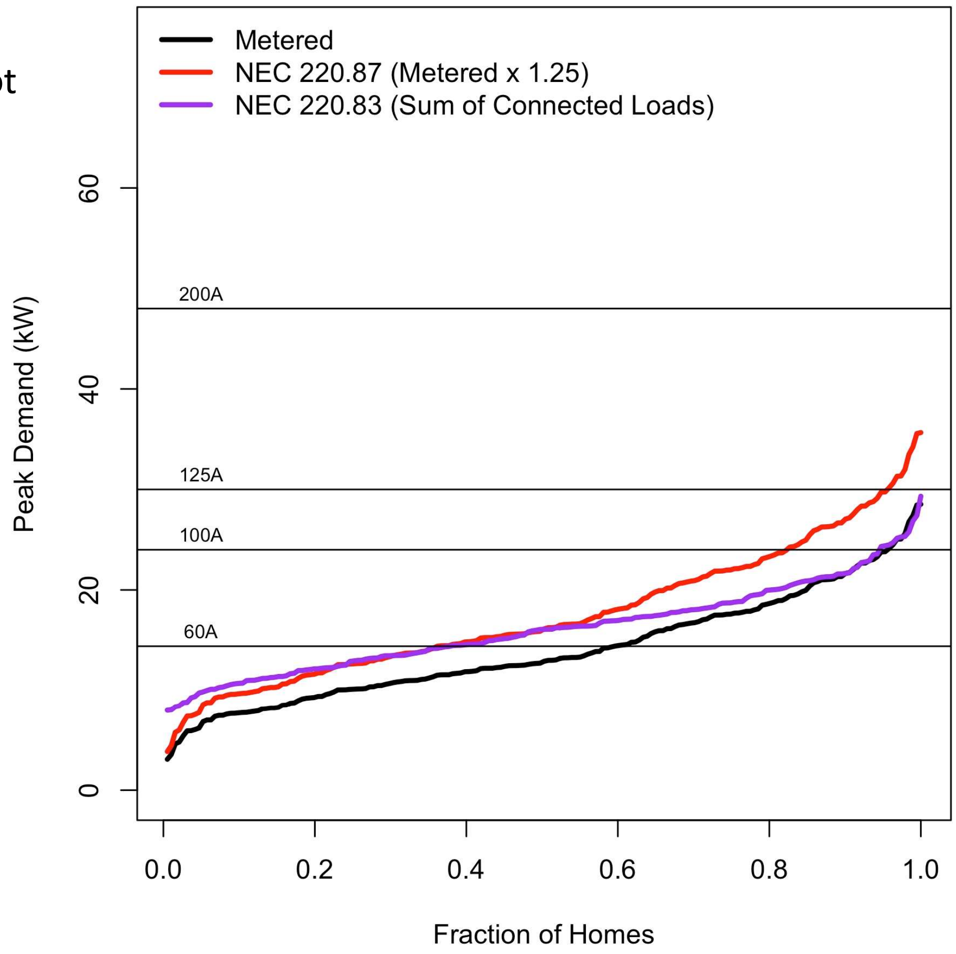
Per NEC 220.87: plenty of room for HPWH

Images from from Josie Gaillard

Comparison of load calculation options

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

Using metered demand does not always result in a lower load



220.87 Determining Existing Loads. The calculation of a feeder or service load for existing installations shall be permitted to use actual maximum demand to determine the existing load under all of the following conditions:

(1) The maximum demand data is available for a 1-year period.

Exception: If the maximum demand data for a 1-year period is not available, the calculated load shall be permitted to be based on the maximum demand (the highest average kilowatts reached and maintained for a 15-minute interval) continuously recorded over a minimum 30-day period using a recording ammeter or power meter connected to the highest loaded phase of the feeder or service, based on the initial loading at the start of the recording. The recording shall reflect the maximum demand of the feeder or service by being taken when the building or space is occupied and shall include by measurement or calculation the larger of the heating or cooling equipment load, and other loads that might be periodic in nature due to seasonal or similar conditions. This exception shall not be permitted if the feeder or service has a renewable energy system (i.e., solar photovoltaic or wind electric) or employs any form of peak load shaving.

(2) The maximum demand at 125 percent plus the new load does not exceed the ampacity of the feeder or rating of the service.

(3) The feeder has overcurrent protection in accordance with 240.4, and the service has overload protection in accordance with 230.90.

Determining Existing Loads

- Overall, improve clarity and usability
- Update language to explicitly allow smart meter data
- Lack of clarity on 60- vs. 15-min data
- Add adjustment from 60- to 15-min
- Clarify calculation procedures when <1-year of data is available
- Add method for solar PV based on peak output of inverter or real-time estimates of output
- Question whether 125% assumption of Continuous Loads is appropriate
- Currently lacks clear discussion of how to account for new loads (explicitly link with 220.83)

220.83 Existing Dwelling Unit. This section shall be permitted to be used to determine if the existing service or feeder is of sufficient capacity to serve additional loads. Where the dwelling unit is served by a 120/240-volt or 208Y/120-volt, 3-wire service or feeder, calculating the total load in accordance with 220.83(A) or (B) shall be permitted.

(A) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is Not to Be Installed. The percentages listed in Table 220.83(A) shall be used for existing and additional new loads.

Load calculations shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m² or 3 volt-amperes/ft² as determined by 220.42
(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)
(3) The nameplate rating of the following:
   a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
   b. Ranges, wall-mounted ovens, counter-mounted cooking units
   c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
   d. Water heaters

(B) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is to Be Installed. The percentages listed in Table 220.83(B) shall be used for existing and additional new loads. The larger connected load of air conditioning or space heating, but not both, shall be used.

Other loads shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m² or 3 volt-amperes/ft² as determined by 220.42
(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)
(3) The nameplate rating of the following:
   a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
   b. Ranges, wall-mounted ovens, counter-mounted cooking units
   c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
   d. Water heaters

Table 220.83(A) Without Additional Air-Conditioning or Electric Space-Heating Equipment

Load (kVA)	Percent of Load
First 8 kVA of load at	100
Remainder of load at	40

Table 220.83(B) With Additional Air-Conditioning or Electric Space-Heating Equipment

Load	Percent of Load
Air-conditioning equipment	100
Central electric space heating	100
Less than four separately controlled space-heating units	100
First 8 kVA of all other loads	100
Remainder of all other loads	40

220.83 Existing Dwelling Unit. This section shall be permitted to be used to determine if the existing service or feeder is of sufficient capacity to serve additional loads. Where the dwelling unit is served by a 120/240-volt or 208Y/120-volt, 3-wire service or feeder, calculating the total load in accordance with 220.83(A) or (B) shall be permitted.

(A) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is Not to Be Installed. The percentages listed in Table 220.83(A) shall be used for existing and additional new loads.

No new A/C or electric heating

Load calculations shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m² or 3 volt-amperes/ft² as determined by 220.42
(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)
(3) The nameplate rating of the following:
    a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
    b. Ranges, wall-mounted ovens, counter-mounted cooking units
    c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
    d. Water heaters

(B) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is to Be Installed. The percentages listed in Table 220.83(B) shall be used for existing and additional new loads. The larger connected load of air conditioning or space heating, but not both, shall be used.

New A/C or electric heating
(always treated at 100% of nameplate rating)

Other loads shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m² or 3 volt-amperes/ft² as determined by 220.42
(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)
(3) The nameplate rating of the following:
    a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
    b. Ranges, wall-mounted ovens, counter-mounted cooking units
    c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
    d. Water heaters

Table 220.83(A) Without Additional Air-Conditioning or Electric Space-Heating Equipment

Load (kVA)	Percent of Load
First 8 kVA of load at	100
Remainder of load at	40

Table 220.83(B) With Additional Air-Conditioning or Electric Space-Heating Equipment

Load	Percent of Load
Air-conditioning equipment	100
Central electric space heating	100
Less than four separately controlled space-heating units	100
First 8 kVA of all other loads	100
Remainder of all other loads	40

220.83 Existing Dwelling Unit. This section shall be permitted to be used to determine if the existing service or feeder is of sufficient capacity to serve additional loads. Where the dwelling unit is served by a 120/240-volt or 208Y/120-volt, 3-wire service or feeder, calculating the total load in accordance with 220.83(A) or (B) shall be permitted.

(A) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is Not to Be Installed. The percentages listed in Table 220.83(A) shall be used for existing and additional new loads.

Load calculations shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m^2 or 3 volt-amperes/ft^2 as determined by 220.42

(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)

(3) The nameplate rating of the following:

a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
b. Ranges, wall-mounted ovens, counter-mounted cooking units
c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
d. Water heaters

(B) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is to Be Installed. The percentages listed in Table 220.83(B) shall be used for existing and additional new loads. The larger connected load of air conditioning or space heating, but not both, shall be used.

Other loads shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m^2 or 3 volt-amperes/ft^2 as determined by 220.42

(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)

(3) The nameplate rating of the following:

a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
b. Ranges, wall-mounted ovens, counter-mounted cooking units
c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
d. Water heaters

Table 220.83(A) Without Additional Air-Conditioning or Electric Space-Heating Equipment

Load (kVA)	Percent of Load
First 8 kVA of load at	100
Remainder of load at	40

Table 220.83(B) With Additional Air-Conditioning or Electric Space-Heating Equipment

Load	Percent of Load
Air-conditioning equipment	100
Central electric space heating	100
Less than four separately controlled space-heating units	100
First 8 kVA of all other loads	100
Remainder of all other loads	40

3 watts/ft^2 for general lighting and plugs. For comparison, Table 220.42(A) lists assumptions for other building types. ALL <2.2 and most 1-1.5 watts/ft^2.

220.83 Existing Dwelling Unit. This section shall be permitted to be used to determine if the existing service or feeder is of sufficient capacity to serve additional loads. Where the dwelling unit is served by a 120/240-volt or 208Y/120-volt, 3-wire service or feeder, calculating the total load in accordance with 220.83(A) or (B) shall be permitted.

(A) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is Not to Be Installed. The percentages listed in Table 220.83(A) shall be used for existing and additional new loads.

Load calculations shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m² or 3 volt-amperes/ft² as determined by 220.42
(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)
(3) The nameplate rating of the following:
   a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
   b. Ranges, wall-mounted ovens, counter-mounted cooking units
   c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
   d. Water heaters

1,500 watts for each small appliance and laundry branch circuit

(B) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is to Be Installed. The percentages listed in Table 220.83(B) shall be used for existing and additional new loads. The larger connected load of air conditioning or space heating, but not both, shall be used.

Other loads shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m² or 3 volt-amperes/ft² as determined by 220.42
(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)
(3) The nameplate rating of the following:
   a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
   b. Ranges, wall-mounted ovens, counter-mounted cooking units
   c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
   d. Water heaters

Table 220.83(A) Without Additional Air-Conditioning or Electric Space-Heating Equipment

Load (kVA)	Percent of Load
First 8 kVA of load at	100
Remainder of load at	40

Table 220.83(B) With Additional Air-Conditioning or Electric Space-Heating Equipment

Load	Percent of Load
Air-conditioning equipment	100
Central electric space heating	100
Less than four separately controlled space-heating units	100
First 8 kVA of all other loads	100
Remainder of all other loads	40

220.83 Existing Dwelling Unit. This section shall be permitted to be used to determine if the existing service or feeder is of sufficient capacity to serve additional loads. Where the dwelling unit is served by a 120/240-volt or 208Y/120-volt, 3-wire service or feeder, calculating the total load in accordance with 220.83(A) or (B) shall be permitted.

(A) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is Not to Be Installed. The percentages listed in Table 220.83(A) shall be used for existing and additional new loads.

Load calculations shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m² or 3 volt-amperes/ft² as determined by 220.42
(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)
(3) The nameplate rating of the following:
   a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
   b. Ranges, wall-mounted ovens, counter-mounted cooking units
   c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
   d. Water heaters

Do we need explicit language addressing EV, stationary batteries, etc.?

(B) Where Additional Air-Conditioning Equipment or Electric Space-Heating Equipment Is to Be Installed. The percentages listed in Table 220.83(B) shall be used for existing and additional new loads. The larger connected load of air conditioning or space heating, but not both, shall be used.

Other loads shall include the following:

(1) General lighting and general-use receptacles at 33 volt-amperes/m² or 3 volt-amperes/ft² as determined by 220.42
(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2)
(3) The nameplate rating of the following:
   a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit
   b. Ranges, wall-mounted ovens, counter-mounted cooking units
   c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)
   d. Water heaters

Table 220.83(A) Without Additional Air-Conditioning or Electric Space-Heating Equipment

Load (kVA)	Percent of Load
First 8 kVA of load at	100
Remainder of load at	40

Table 220.83(B) With Additional Air-Conditioning or Electric Space-Heating Equipment

Load	Percent of Load
Air-conditioning equipment	100
Central electric space heating	100
Less than four separately controlled space-heating units	100
First 8 kVA of all other loads	100
Remainder of all other loads	40

Energy Management Systems

From Article 750

(1) Current Setpoint. A single value equal to the maximum ampere setpoint of the EMS shall be permitted for one or more of the following:

(1) For calculating the connected load per 220.70
(2) For the maximum source current permitted by EMS control

From Article 220

220.70 Energy Management Systems (EMSs). If an energy management system (EMS) is used to limit the current to a feeder or service in accordance with 750.30, a single value equal to the maximum ampere setpoint of the EMS shall be permitted to be used in load calculations for the feeder or service.

The setpoint value of the EMS shall be considered a continuous load for the purposes of load calculations.

Energy Management Systems

From Article 750

(1) Current Setpoint. A single value equal to the maximum ampere setpoint of the EMS shall be permitted for one or more of the following:

(1) For calculating the connected load per 220.70
(2) For the maximum source current permitted by EMS control

Does a single value really suffice?

From Article 220

220.70 Energy Management Systems (EMSs). If an energy management system (EMS) is used to limit the current to a feeder or service in accordance with 750.30, a single value equal to the maximum ampere setpoint of the EMS shall be permitted to be used in load calculations for the feeder or service.

The setpoint value of the EMS shall be considered a continuous load for the purposes of load calculations.

How do we account for tech that controls only certain loads (e.g., EV and DHW) based on the whole dwelling real-time demand?

What About Different Load Types Adding Differently?

- HVAC, EV, DHW, Laundry and Cooking might add very differently.
- Currently the code recognizes HVAC as being different and treats it with a 100% multiplier.
- We could derive distinct slope/multiplier values for different load types, if this is justified in the data.
  - New Peak = Intercept + 0.8 x HVAC + 0.5 x DHW + 0.95 x EV + 0.2 x All Others
  - This increases complexity and makes analysis more difficult.

Predicting 15-minute from 60-minute peak demand data (add as option in NEC 220.87)

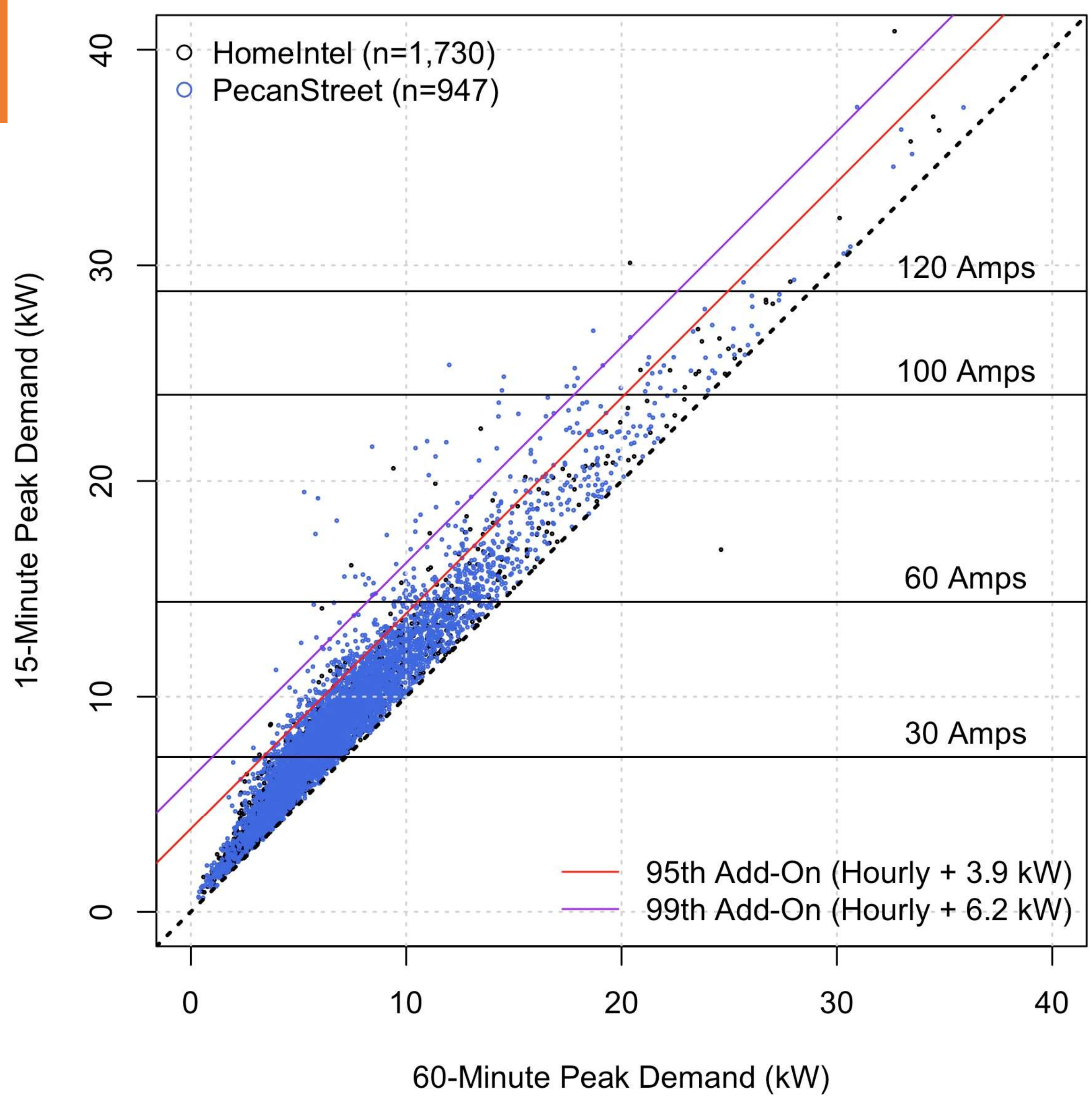
- The current electrical code allow us to use 15-minute dwelling peak demand data in determining the existing load on a service. But the vast majority of household smart meters produce hourly data…

- Derive conversion based on homes with both the 15-minute and 60-minute whole-dwelling peak demand
  - HomeIntel (HEA) (n=1,730)
  - Pecan Street Dataport (n=947)
  - NEEA EULR (n=210)
  - Efficiency Vermont (n=???)
  - Lumin smart panel (n=???)
  - Others?

- To be sufficiently conservative in the code
  - We ARE NOT looking for the best prediction (minimize error)
  - We ARE looking for the prediction that almost never under-estimates the 15-minute value
  - We DO need to choose an approach based on how it treats low- vs high-demand homes

Using Metered Data

Predicting 15-minute from 60-minute peak demand data



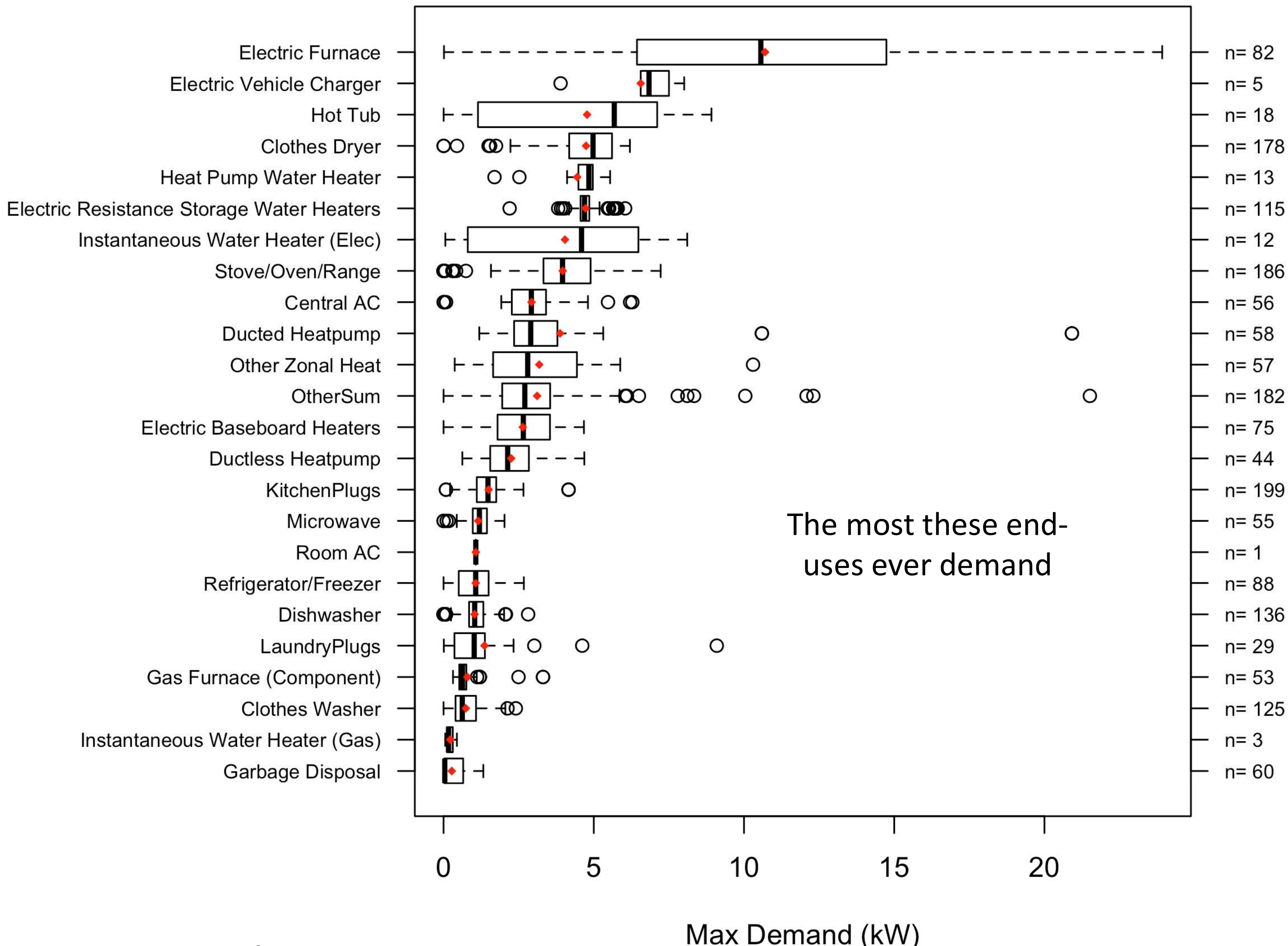
Load Fractions by End-Use Type

- “Load fractions” (LF) are used in the NEC to estimate the amount of load that is added to the dwelling peak.
  - E.g., 5 kW resistance water heater, with a load fraction of 0.6, adds 3.0 kW to the peak (5*0.60)
  - “Standard” LF look at the demand of each device during the peak period – appropriate for existing loads
  - “Synthetic” LF compare dwelling peak demand with and without the device – appropriate for retrofit assessments

- NEEA EULR data
  - 210 homes in the Pacific Northwest with select electrical end-uses (e.g., heat pumps, resistance water heating)
  - 2018-2022 (ongoing)
  - End-use circuit sub-metering
  - 15-minute time-step
  - ***ALL RESULTS ARE PRELIMINARY, MAY INCLUDE ERRORS, AND ARE SUBJECT TO CHANGE !!!!***

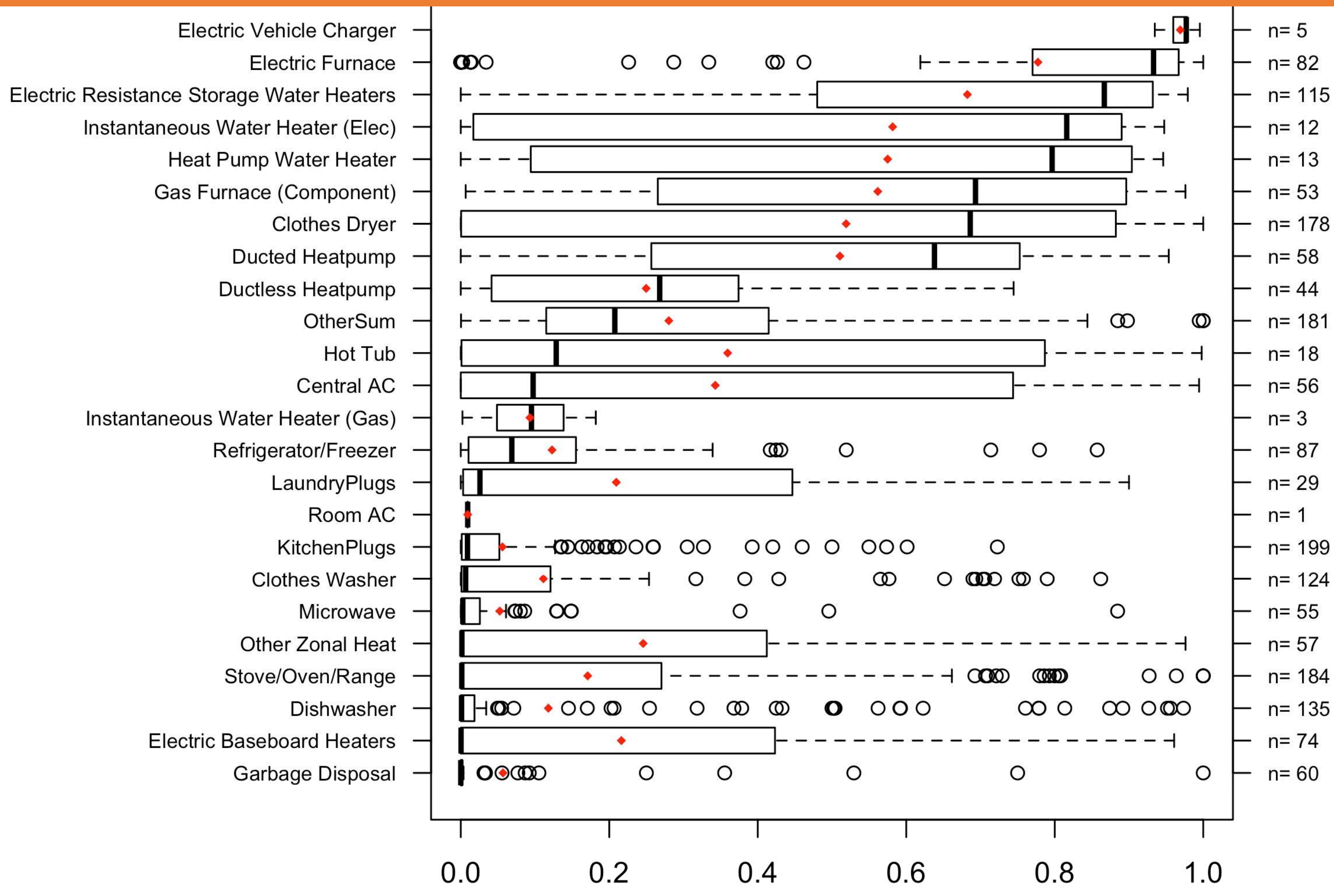
- Other end-use data sets to be analyzed
  - Pecan Street Dataport (n=957) (analysis is 80% complete)
  - Lumin Smart Panel (n=???) (working on NDA) (strong source for EV data)
  - Efficiency Vermont dwelling peak demand data before and after heat pump retrofits (n=???)

https://neea.org/data/nw-end-use-load-research-project/energy-metering-study-data#



PRELIMINARY, SUBJECT TO CHANGE!

Compared to Its Maximum Demand, How Much Do End-Uses Operate During the Dwelling Peak?



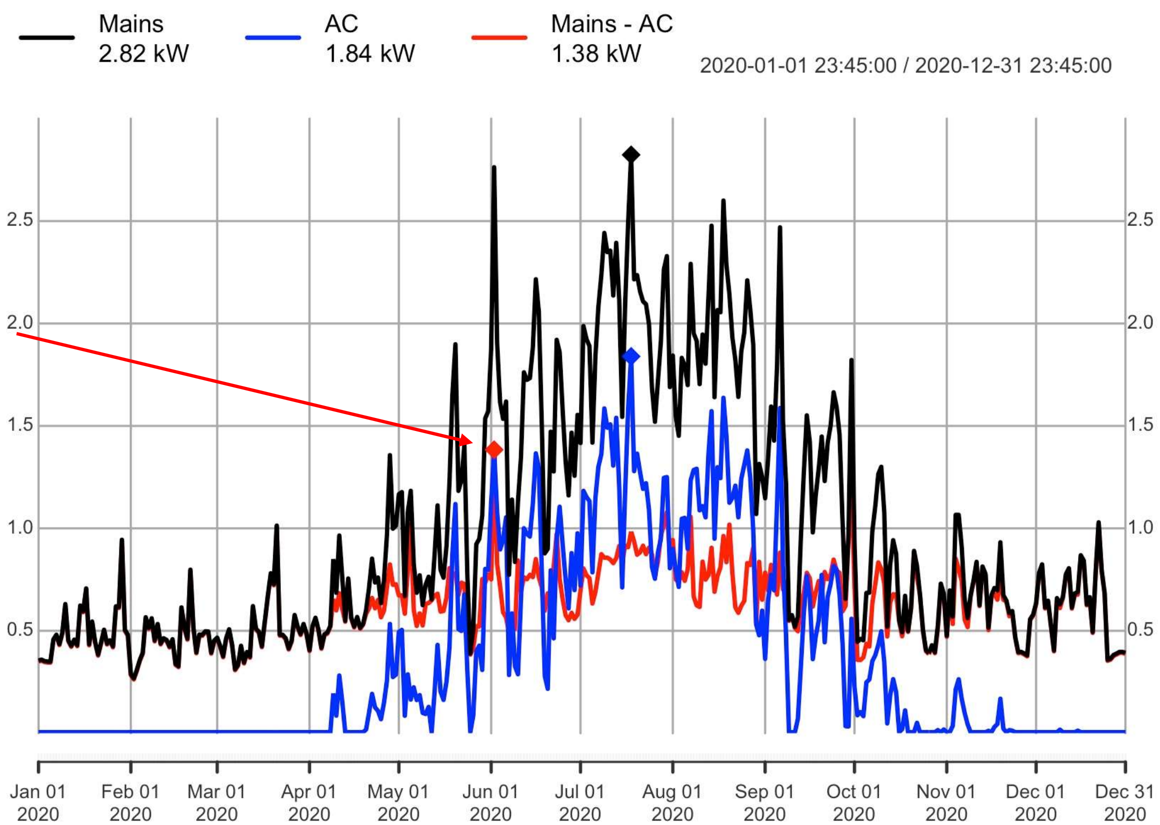
$$\frac{\text{End-use during dwelling peak}}{\text{End-use maximum}}$$

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

When the Home Peaks, most appliances and plugs are off

Calculating Standard and Synthetic Load Fractions

Dwelling peak that would have occurred without the AC installed ("pre-retrofit")

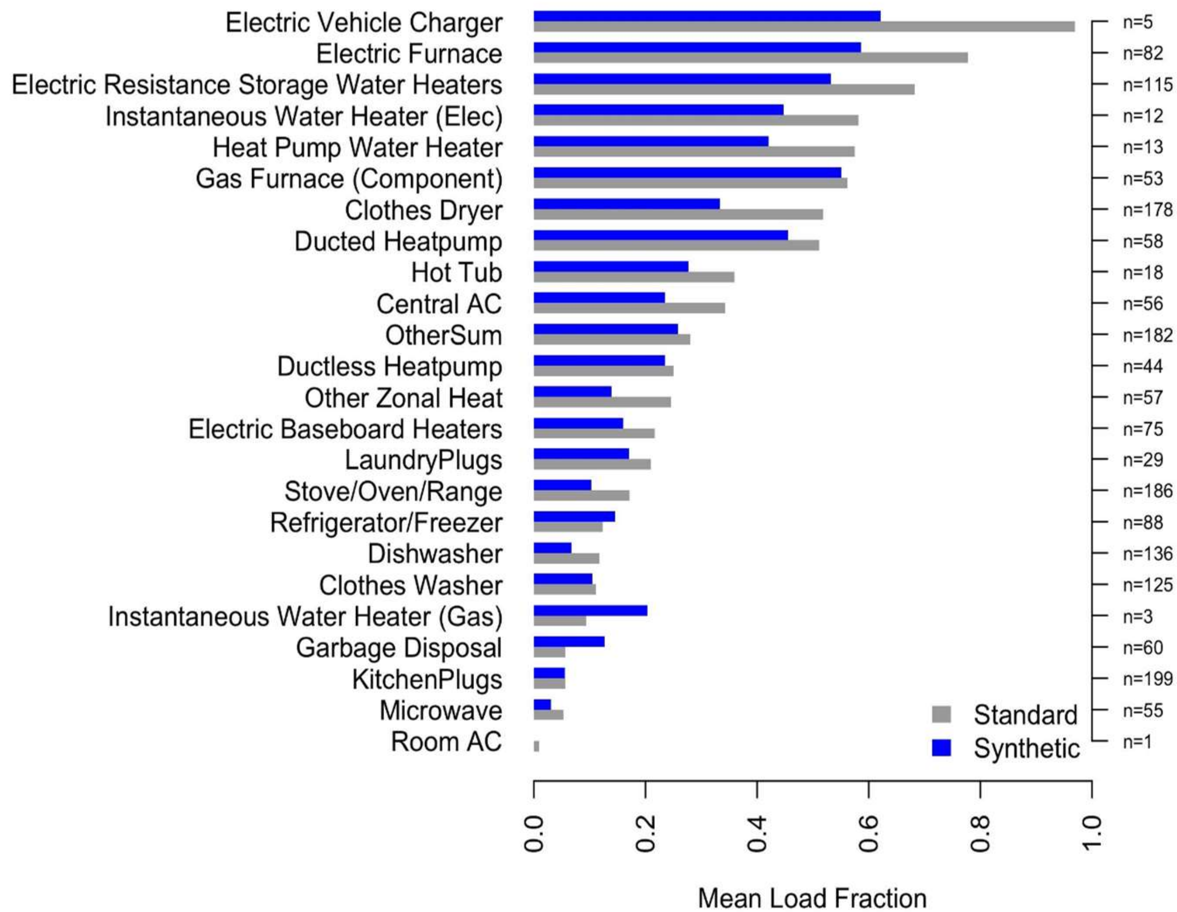


- Mains Peak
  - 2020-07-18 23:45
  - 2.82 kW
- AC max and peak
  - 2020-07-18 23:45
  - 1.84 kW
- Mains – AC peak
  - 2020-06-02 23:45
  - 1.38 kW
- AC Contribution to Peak
  - 2.82 – 1.38 = 1.44 kW
- Load Fractions
  - Standard: 1.84 / 1.84 = 100%
  - Synthetic: 1.44 / 1.84 = 78%

Load Fractions by End-Use Type

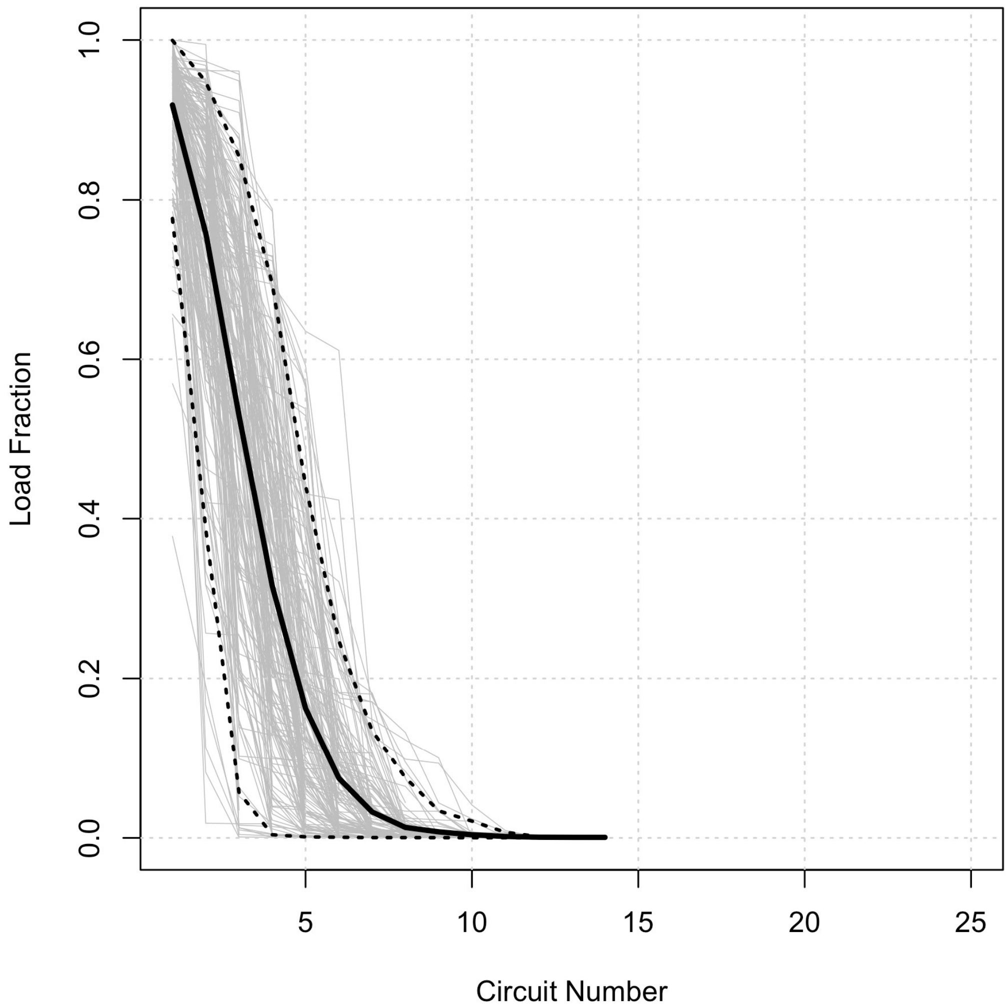
Initial Thoughts on End-Use Load Fractions

- Three categories to include in NEC calculations:
  - Household appliances: **<20%**
  - Thermostat-controlled devices: **40-60%**
  - Electric vehicle charging: **100%**
- Other data sources will be analyzed and merged with the EULR data using standardized end-use categories



https://neea.org/data/nw-end-use-load-research-project/energy-metering-study-data#

Almost never are very many loads near their maximum demand



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
- We need rebates for ***avoiding*** panel replacement
  - 120V HPWH
  - Small split HP systems
  - 120V cooking
  - Battery and energy storage systems (whole home or in appliances)
  - EV pausers
  - Meter collars
  - Reduces grid stress in the future as we electrify
- Eliminate incentives for 200 -> 300Amp panel upgrades

Want to Be Involved?

- Share data (panel amperage, peak data, end-uses)
- Review draft code language prior to sharing with NFPA (before April 2023)
- Local adoption of code provisions:
  - Advocate with the California Building Standards Commission
  - Convene national code stakeholders group to support local adoption of low-power provisions prior to 2026 code launch

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**

Rewiring Communities:

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

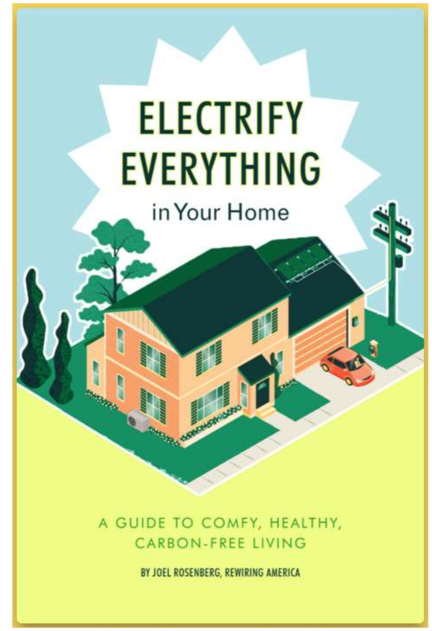
[1] Adam Zurofsky,[2] Jeffrey Schub,[3] John Rhodes,[4] Tony Curnes,[5] and Sam Calisch[6]

Resources

https://www.natethehousewhisperer.com/electrify-everything-course.html

THE SWITCH IS ON

https://www.switchison.org/



https://www.rewiringamerica.org/electrify-home-guide

BUILDING DECARBONIZATION COALITION

Questions?

Extra slides

Breaker curve

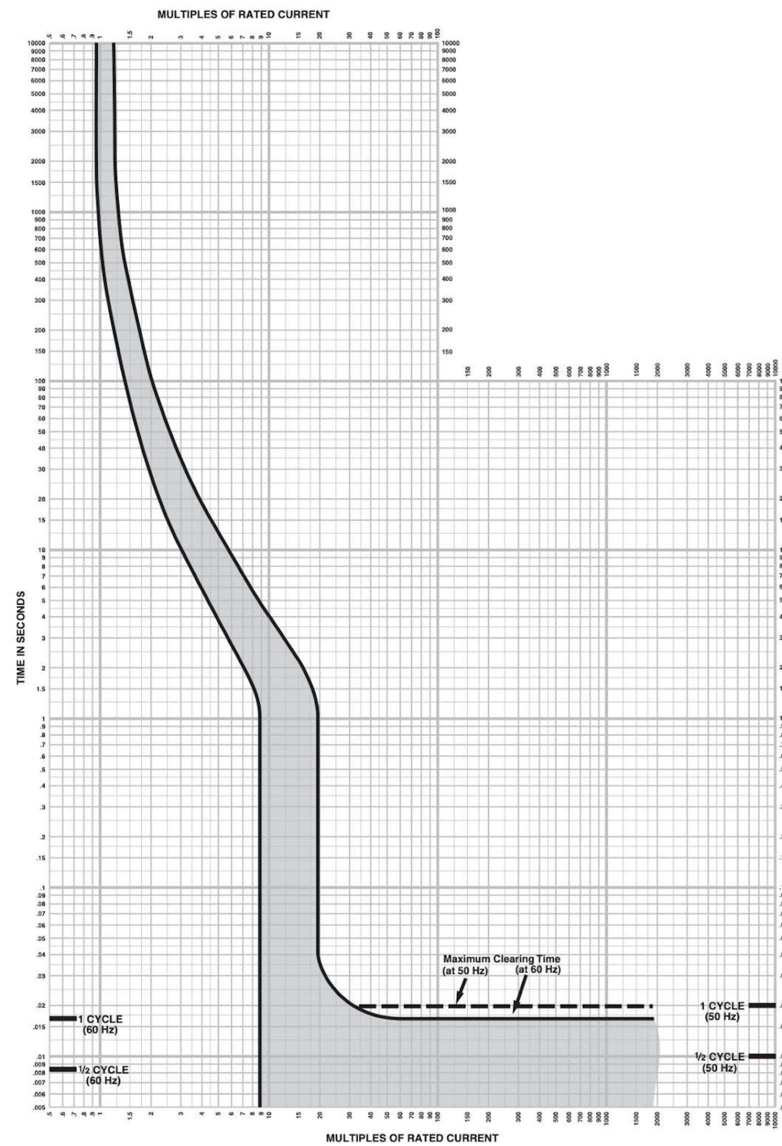


Figure 1: Thermal-magnetic Time/Current Characteristic Curve

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, a kitchen range that combines an induction cooktop with an oven on a single circuit, or replacing a 240 volt oven with 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, like EV chargers, heat pumps, and induction cooktops. If panel capacity is limited, spend more for the most efficient versions of each appliance since it can avoid much more expensive panel upgrade costs.

Findings About Costs - Homeowner Side

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

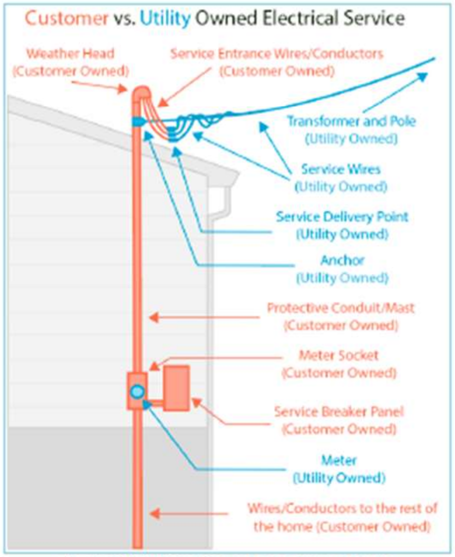
Cost Description	Average cost	Transaction
Homeowner Equipment Service Upgrade Fee	$1,300 - $5,000	Homeowner → Contractor
Breaker Panel Upgrade	$1,300 - $5,000	Homeowner → Contractor
Upgrade/New Branch Circuits	$250 - $700 per circuit	Homeowner → Contractor
Permit Costs	**PG&E Territory**: $125 - $500 **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

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

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**

NV5

CONTRIBUTORS

NV5 INC.
Shoshana Pena, Director of Program Services
Collin Smith, Program Manager
Greg Butsko, Vice President of Distribution Services
Rick Gardner, Director of Distribution Services

REDWOOD ENERGY
Sean Armstrong, Principal
Emily Higbee, Research Director
Dylan Anderson, Senior Staff Researcher
Rebecca Hueckel, Senior Staff Researcher

PROJECT SPONSORS
Pacific Gas and Electric Company: Robert Kasman, Victoria Culter, and Kati Pech
San Diego Gas and Electric Company: Kelvin Valenzuela and Dan Hudgins