HVAC Heat Pump Upgrades and their Impact on Household Maximum Power Demand

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ACEEE Summer Study, Panel 2

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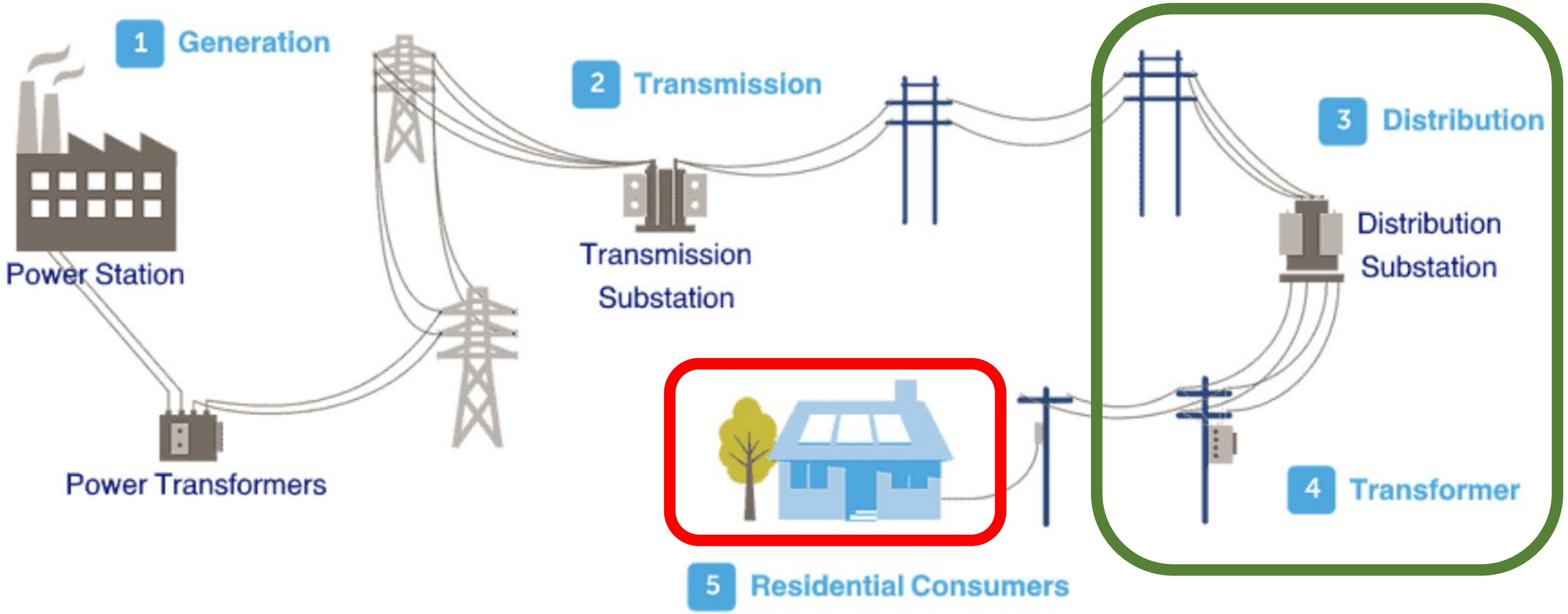
Outline

- Background on HVAC heat pumps and household power demand
- Methods and datasets (VEIC, Pecan Street and NEEA EULR)
- HVAC Heat Pumps in Sub-metered Dwellings
- HVAC Heat Pumps in Vermont Dwellings
- Conclusions

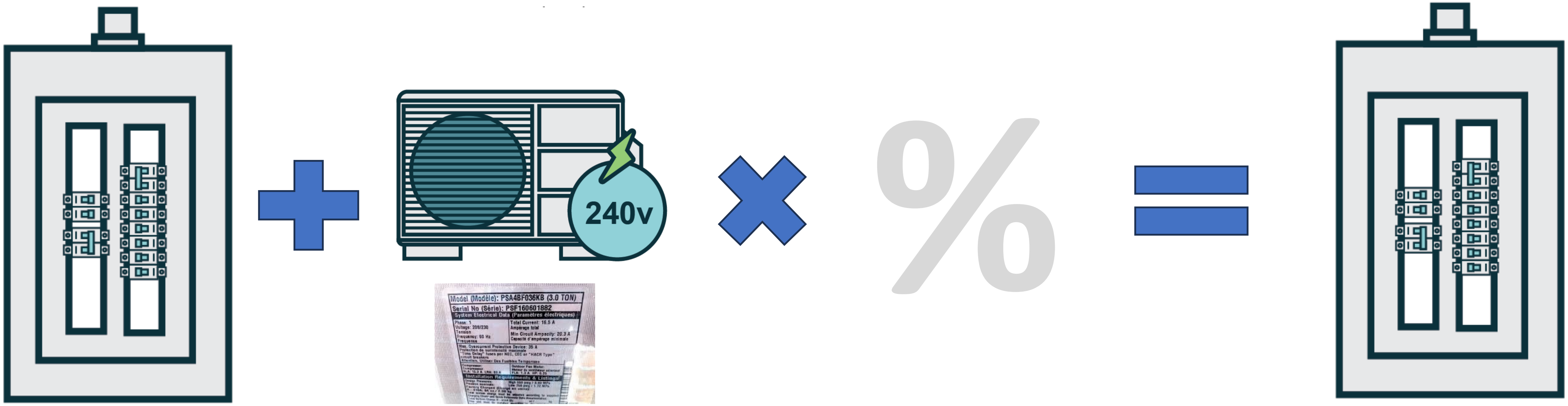
Background



- New HVAC heat pumps can impact:
  - Grid loads (some past research)
  - Household loads (not yet studied)
- Why do we care about household maximum demand?
  - Drives infrastructure costs and time delays during HVAC heat pump deployment
    - Panel replacements are commonly $2-10k ($3,500 typical), without grid costs
    - Potential time delays of weeks to months/years
  - The National Electric Code (NEC) (NFPA 70) is used to evaluate the need for local infrastructure upgrades

Image credit: https://www.electricaltechnology.org/2021/10/electric-power-distribution-network.html

Current Treatment of HVAC Heat Pumps in the NEC



Existing Load
12 kVA
(50A, 240V)

New Heat Pump Load
5.5 kVA
(23A, 240V)

NEC Demand Factor
100%

New Load
17.5 kVA
(73A, 240V)

Current Treatment of HVAC Heat Pumps in the NEC

Is this value appropriate?

Do HVAC heat pumps behave this way in reality?

Is this conservative approach necessary for safety?

Is there an alternative that reduces unnecessary panel replacements while being safe?

<u>NEC Demand Factor</u>

100%

Data Sources

NEEA End-Use Load Research (EULR)

- Detailed sub-metering data
- No actual retrofits
- 181 highly-electrified dwellings in Pacific Northwest (OR, WA, ID, MT)

Pecan Street Dataport

- Detailed sub-metering data
- No actual retrofits
- 776 conventional dwellings across US (mostly TX, smaller numbers in CA, NY, CO)

VEIC ccASHP

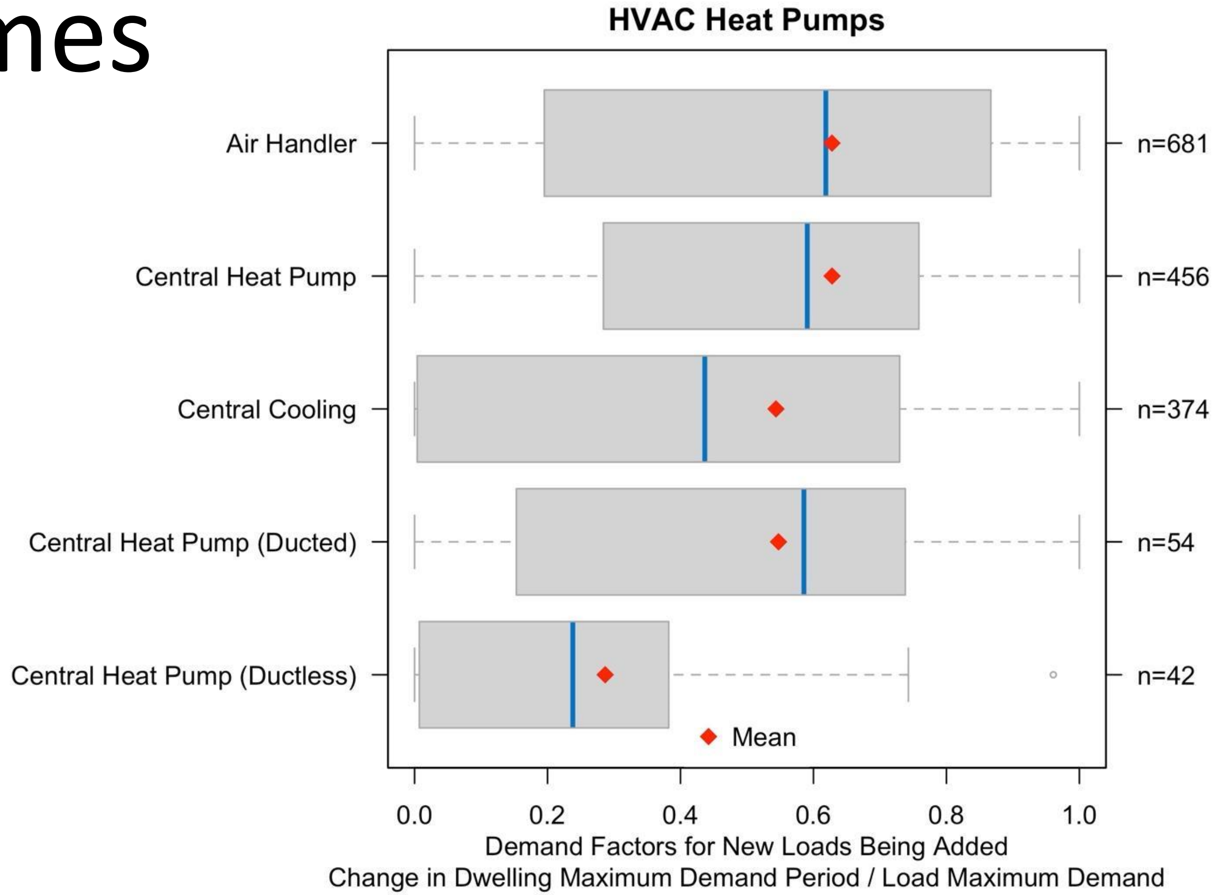
- Smart meter 15-minute interval data
- Actual cold climate heat pump upgrades
- 9,093 Vermont dwellings (includes some multi-family)
- Dwelling maximum demand values derived from smart meter data before and after incentivized installation of cold climate heat pumps

Calculating HVAC Heat Pump Demand Factor

$$Demand\ Factor\ (\%) = \frac{Change\ in\ Dwelling\ Maximum\ Demand_{kW,post-pre}}{Maximum\ HVAC\ Heat\ Pump\ Demand_{kW}}$$

End-Use Sub-Metered Homes

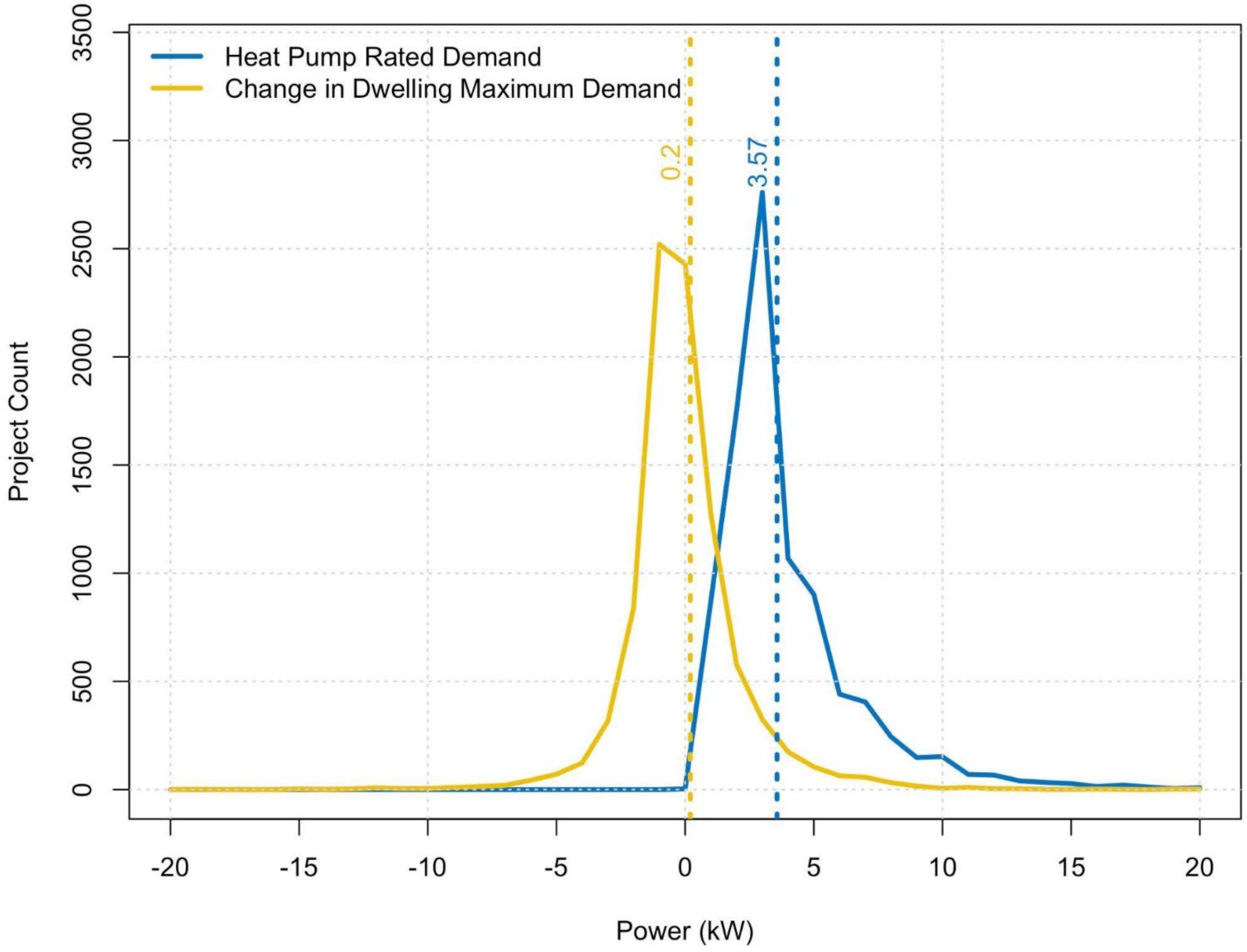
- HVAC heat pump demand factors are widely varying (30-70%)
- Ductless heat pumps show lower demand factors (25%)
- **Proposed value of 50% for all new loads**, based on this and other end-uses



Load Names	*Number of Systems*	*Load Maximum Demand (kW)*	*Change in Whole Dwelling Maximum Demand When New Load is Added (kW)*	*Demand Factor for New Load Being Added*
Air Handler	681	0.70	0.46	62%
Central Heat Pump	456	2.99	1.52	59%
Central Cooling	374	2.80	1.13	44%
Central Heat Pump (Ducted)	54	2.88	1.50	59%
Central Heat Pump (Ductless)	42	1.85	0.40	24%

VEIC ccASHP Heat Pump Rated Demand vs. Change in Dwelling Demand

- Change in dwelling maximum demand (0.2 kW) is much less than the HVAC heat pump name-plate rating (3.6 kW)
  - ~5% demand factor
- Roughly half of homes reduce demand after installing HVAC heat pump
- Small minority of homes increase demand by more than the HVAC heat pump rating
- Why?
  - Adding/removal of equipment we do not track (e.g., AC)
  - Year-on-year variability in max demand
  - Do other end-uses drive peak (electric clothes dryers, electric cooking, resistance heaters, etc.)?



Hypothetical Panel Upsizing Assessment

- Goal is to estimate impacts of the current 100% demand factor vs the proposed 50% value
- Actual panel ratings are unknown
- Panel upsizing need determine by metered pre-heat pump demand plus the heat pump rating at either 100% or 50% and threshold of 100A (24 kW)

- **Remain at 100A**: Pre-heat pump load <= 24 kW and Post-heat pump load <= 24 kW
- **Remain at 200A**: Pre-heat pump load > 24 kW
- **Replace 100A with 200A:** Pre-heat pump load <= 24 kW and post-heat pump load > 24 kW

Panel Status	***100% Demand Factor (current)***	***50% Demand Factor (proposed)***
Remain at 100A	91.8%	95.8%
Remain at 200A	2.7%	2.7%
Replace 100A with 200A	5.5%	1.6%

Evaluating the Necessity of Panel Upsizing

- **Unnecessary panel replacements:** Homes with panel replacements where the actual post-heat pump maximum dwelling metered demand was <= 24 kW.
- **Necessary panel replacements**: Homes with panel replacements where the actual post-heat pump maximum dwelling metered demand was > 24 kW.
- **Missed panel replacements**: Homes that remained at 100A where the actual post-heat pump maximum dwelling metered demand was > 24 kW. If these homes actually had 100A panels, they might experience an overload condition or trip a main breaker on rare occasions.

	100% Demand Factor (current)	***50% Demand Factor (proposed)***	***Difference in Demand Factors***
Unnecessary panel replacements	5.42%	1.50%	3.92%
Necessary panel replacements	0.11%	0.07%	0.04%
Missed panel replacements	0.14%	0.19%	-0.04%

Panel Upsizing Results in VT ccASHP Homes

- Using either demand factor:
  - Most dwellings remain at their current panel rating (94.5 to 98.5%)
  - Of the small number of panel replacements (1.5-5.5%), most appear unnecessary based on actual post-installation metered demand (96-98%)
  - Necessary panel replacements (0.07-0.11%) and missed panel replacements (0.14-0.19%) are very uncommon.
- Across 10,000 dwellings, the 50% demand factor leads to:
  - 5 additional missed replacements (0.05% of all dwellings)
  - 392 fewer unnecessary panel replacements (3.9% of all dwellings)
  - Estimated cost savings of $1.4 million
- Missed replacements occur even with the 100% demand factor. Perfect safety does not appear possible.

Conclusions

- New electrical loads add less than their nameplate rating
  - “In the wild” ccASHP in VT added <10% of nameplate rating
  - “Controlled” sub-metering assessment shows ~40-60% of nameplate rating
- Proposed treatment of HVAC heat pump loads at 50% demand factor
  - Provides similar electrical safety
  - Reduces panel replacements and other infrastructure costs
  - Facilitates faster, cheaper installation of HVAC heat pumps in existing dwellings
  - Very slightly increases the missed panel replacements and potential for breaker trips
- Notes/caveats:
  - VT ccASHP retrofits potentially confounded by backup heating sources, changes in other loads not observed in the study, year-on-year variability in power demand.
  - Reported Demand Factors are likely low, because actual HVAC heat pump power demand is typically < nameplate power rating used in NEC calculations

THANK YOU

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Calculation Methods – End-Use Sub-Metering

- Maximum HVAC Heat Pump Demand
  - Maximum 15-minute sub-metered real power for each HVAC heat pump.
- Change in Dwelling Maximum Demand
  - No heat pump retrofits occurred, required “synthetic” retrofit analysis.
  - Dwelling maximum demand is calculated for two time-series:
    1. Whole dwelling with the HVAC heat pump
    2. Whole dwelling with the sub-metered HVAC heat pump subtracted at each time-step
  - #1 minus #2 is change in dwelling maximum associated with the HVAC heat pump
- Notes/Caveats
  - Provides a highly controlled estimate of Demand Factor
  - Sub-metered 15-minute real power likely an underestimate of nameplate power rating.
  - No actual retrofits/upgrades occurred.
  - “Synthetic” retrofit approach does not account for electrical loads that would have been present pre-heat pump (e.g., furnace air handler).

Calculation Methods – VEIC ccASHP – Smart Meter Data

- Maximum HVAC Heat Pump Demand
  - Look up of maximum power draw from test conditions in NEEP ccASHP database.
- Change in Dwelling Maximum Demand
  - Maximum 15-minute demand from the year immediately after minus the year immediately before heat pump upgrade.
- Notes/Caveats
  - Provides an “in the wild” (i.e., messy) estimate of Demand Factor
  - NEEP ccASHP database likely an underestimate of nameplate power rating.
  - We lack important information about the VT homes, including presence of other large electrical loads, provision of strip heat, presence of other backup heat sources, configuration of heat pumps, etc.

Electric Loads in Sub-Metered Homes

Source	Electric End-Use Count and Frequency*					Total
	Space Heating	Space Cooling	Water Heating	Clothes Drying	Cooking	
NEEA EULR	137 (76%)	49 (27%)	125 (69%)	165 (91%)	154 (85%)	181
Pecan Street	444 (57%)	286 (37%)	148 (19%)	406 (52%)	398 (51%)	776
All	581 (61%)	335 (35%)	273 (29%)	571 (60%)	552 (58%)	957

Source	Combined Electric End-Use Count and Frequency*			Total
	Space Heating And Water Heating	Space Heating And Water Heating And Clothes Drying	Space Heating And Water Heating And Clothes Drying And Cooking	
NEEA EULR	114 (63%)	111 (61%)	105 (58%)	181
Pecan Street	106 (14%)	53 (7%)	42 (5%)	776
All	220 (23%)	164 (17%)	147 (15%)	957